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Shelter-environmental influence on swine growth

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SHELTER-ENVIRONMENTAL INFLUENCE ON SWINE GROWTH

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INTRODUCTION

The design of farm structures for efficient animal production requires a prior knowledge of the reactions of the animals housed to the environment which will be obtained. It is well known that domestic farm animals have a comfort zone, varying with such factors as species, breed, activity, and age where the production efficiency of the animal is at its highest. This optimum environment (thermoneutrality) is normally rather broadly defined by dry bulb air temperature and relative humidity.

The added cost of production due to a lack of good environment on the farm is unknown, nor is it well known what losses may result with degrees of deviation from the optimum. Extensive tests using pyschrometric and psychroenergetic laboratories are beginning to establish environmental-physiological reactions of some of the more popular production type animals, indicating poor environment greatly increases the cost of production. The natural environmental variations which occur under normal production practice and which can relax or increase thermal stresses for intervals of varying duration are not duplicated in such tests.

Most environments tend to be judged by dry bulb air temperature. Animals are then said to possess a critical temperature above or below which production efficiency declines rapidly. Yet general observations of animals exposed to temperatures well above and below this critical point for short periods of time indicate no apparent deleterious effects. Use of artificial sources, such as heat lamps which alter radiant energy exchange, has also been shown to eliminate serious stressing when air temperatures are far below the critical. It has also been demonstrated (11, p.125) that different combinations of dry and wet bulb temperatures and air movement (effective temperature) produce very similar comfort conditions for humans. Most species of domestic production animals depend greatly on heat loss through respiration during hot weather. As such the air moisture content might be quite important in their comfort, yet this factor can not be evaluated by dry bulb temperature alone.

Probably of greatest concern to the producer is the ratio of production to feed consumption. Broadly speaking, animals are heat engines. They consume feed and convert it into produce of one form or another and heat energy. If environment is such that the normal operation can continue with a minimum of energy required for non-production purposes, the quantity of feed energy for production is a maximum. Thus if additional energy is required to maintain body temperature, a non-productive reaction requiring feed energy, efficiency is lost.

With the foregoing in mind, it appeared justifiable to test for the influence of some of these other environmental factors, restricting the study to one popular species of production animal. As swine are being produced more and more in confinement, are apparently easily influenced by environment, are one of the most numerous domestic production animals, and normally reach market weight at less than 6 months of age so that independent tests may be made for summer and winter conditions with the same facilities, this species was selected.

A study of factors in a varying environment as induced by normal weather would require the use of a large number of animals, sufficiently replicated, to permit statistical treatment due to the number of uncontrollable variables. By meeting these statistical needs, however, measurements of the various factors which might accurately describe the environments could be made and these measurements correlated for significance against the feed consumption and weight gain data. Those measurements found to have noticeable influence could then be used to develop a prediction equation relating their influence on weight gain and feed consumption, and results using this equation also compared to those found in other studies for reliability of application. This information would supply the producer with a better understanding of environment and its constituent parts and an index to judge the economy of controlled as against uncontrolled or partially controlled environment in animal structures.

Therefore, the purpose of this work was to develop relationships of the air temperature, relative humidity and radiant temperature to overall environment in swine buildings using a statistically established number of animals and buildings, and to predict from these tests the effect of different environments under naturally varying conditions on the efficiency of this domestic production animal.

HISTORICAL

Project 1244, "The Effect of Selected Building Materials Upon the Growth and Development of Swine", was started by the Iowa Agricultural Experiment Station in 1952. The project was sponsored by the Reynolds Metals Company, and its purpose was to evaluate the properties of aluminum and other materials for effect on the environment and the nutritional efficiency of swine. In very limited studies conducted in several areas of the United States, reports of results indicated that swine respond differently when housed under different materials. None of these tests had sufficient control to evaluate these differences, however, and the Reynolds Metals Company desired to obtain more accurate measure to aid in evaluation of the potential usage of aluminum.

At the same time, college experiments in swine nutrition were indicating that the effect of some of the feed ingredients was being confused by other things, and it was felt that environment might be the strongest contributor. Therefore, the Animal Husbandry and the Agricultural Engineering Departments at Iowa State College jointly took responsibility under this project. The first phase is to establish what differences in development of animals of the same breed and hereditary characteristics fed on the same ration are due to environment; and the second phase is to study nutritional requirements of swine knowing the expected variability caused by environmental differences.

This thesis is an analysis and discussion of the first summer and winter tests under phase one, the completion of phase one necessarily dependent upon the results of this analysis and the evaluation of more tests.

REVIEW OF LITERATURE

Tests performed on domestic animals normally can be classified as those in which the environment is controlled, and those in which the environment is not controlled but allowed to vary as might occur under present production practices. D. H. K. Lee, Head, Physiology Department, University of Queensland, Brisbane, Australia, while on special assignment with the Food and Agriculture Organization of the United Nations, and R. W. Phillips, then Acting Director of the Food and Agriculture Organization, in a general review of the problem of associating animals with their environment, made the following statement (18, p.411):

> Observations made under natural conditions, upon animals living a free life and not subjected to the artificialities usually inherent in laboratory examination, undoubtedly have an appeal to those who are themselves concerned with hard practical problems. There is no doubt, moreover, that field observations are of prime importance to the study of animal adaptation. The practical problems arise in the field; any suggestions for action must be tested out in the field and must be compatible with field conditions. Field studies have one serious inherent drawback, however, in that there is an enormous and uncontrolled, often unmeasured, variability in a large number of influential conditions. This makes results very difficult, sometimes impossible, to interpret if considered without reference to more exact experimental enquiries.

These same authors (18, p.415) have the following to say concerning the laboratory approach:

> By contrast with field observations, laboratory experiments are ideally suited to the detailed analysis of specific reactions to specific conditions, and to the systematic plotting of the interactions of a small number of controllable variables. Undoubtedly, the

> rigid control of variables itself renders the conditions "unnatural," but, properly used, the laboratory can greatly advance our understanding of field problems as well as of that fundamental scientific knowledge without which conquest of the environment would be slow indeed. Detailed experiment upon a carburetor does not teach one to drive a car, but without it cars would be poor performers.

Brody and others (22) have done extensive work on dairy animals using a psychroenergetic chamber, but of closer relation to this study are the tests of Kelly and associates (16) using a psychrometric chamber to determine the effects of air temperature and relative humidity on swine.

Lee and associates (17) have tested under laboratory conditions the reactivity of animal functions to a rise in atmospheric temperature and relative humidity and have classified animals on the basis of an R factor of which pigs fall into the rapid rectal temperature rise, rapid respiratory rise group. This work uses a method of exposing the animal for seven hours at the particular condition. Results show that the rise in rectal temperature is only slight at temperatures of 90^{o} or less and 65 percent relative humidity but rises quite rapidly after stressing for a period of two hours in temperatures of 95^{o} or above.

On the other hand the work of both Brody and Kelly has largely been done by allowing acclimatization of several days with continued subjection of the animal to the particular condition for periods of one week or more.

Heitman and Hughes (12), using the same facilities as those used by Kelly, reported effects of air temperature and relative humidity on swine with temperature limits of 40° to 115°F. and two relative humidities of 30 and 94 percent. They found that the optimum temperature for the pigs under test was approximately 75°F., and that feed efficiencies and average daily gains dropped quite rapidly as temperatures were increased or decreased from that point. They found no apparent effect of relative humidity except when the temperature was extremely high, 96°F., and the relative humidity raised to approximately 94 percent. Animals were so distressed that the test was interrupted to prevent possible death. They also found that moisture on the floor, which increased the evaporation loss from the skin, permitted the increase of the environmental temperature to 115°F., whereas on dry floors the upper limit was approximately 100°F.

Kelly and associates (16) partitioned heat loss from pigs, and this work is referred to at appropriate points in this thesis.

Tidwell and Fletcher (27) reported on the effect of summer environment on the body temperature and respiration rate of swine. Their study, based on observations of a limited number of animals, indicated that the rectal temperature and respiration rate rise quite sharply on exposure to sunlight.

Lucas and Thompson (19) ran experiments on three sows and their litters to determine the value of a warm floor in hog production. They found that baby pigs on cold concrete floors seem to have a higher incidence of liver disease than those raised on the wood or electrically warmed floors, but that upon reaching weaning age and on to market weight there was no difference in the rapidity of growth.

McLagan and Thompson (21) conducted winter tests with sows and litters in enclosures under normal climatic variations to determine if effective temperature, as measured by combination of globe, Kata, and silvered bulb thermometers, could be related to the growth rate from birth to weaning age. They were not able to show definite response, but indications were that the best gains occurred in the higher effective temperatures.

Brody (3) has brought together vast amounts of information on the physiological behavior of animals, excellently summarizing this vast field, analyzing the information from the engineering, chemical and agricultural viewpoints, and presenting many selected references directed primarily toward the animal physiology field. Brody describes pigs as having one of the higher gross energetic efficiencies of growth among common domestic production animals, gross efficiency being the pounds of gain per pound of feed consumed. In this same text Brody discusses methods of determining the surface area of an animal based on actual experimental measurements, and goes into detail concerning the departure of their actual surface area from that as would be derived by elementary dimensional analysis in which symmetry is assumed; stating that elementary dimensional analysis implies symmetrical bodies and that animals are not symmetrical.

Bond and others (2) studied the radiation intensities under open shades and indicate that painting of the exterior shade surface white and the underside black yields the lowest intensity upon the animals sheltered and also is accompanied by an air temperature reduction. However, their shades were surrounded by bare hot ground, and indications are that the re-radiation from this hot surface reflected by a low emissivity underside may have been responsible for higher readings than would be obtained where such under surfaces were part of a complete enclosure.

In general published information on investigations of environment for effect on animals agrees to the following points:

1. Animals are more tolerant to conditions where temperatures are below the optimum than to those above the optimum.
2. Relative humidity does not appear to be important except when accompanied by high temperature.
3. Aiding an animal to lose heat by evaporation from the body surface, either by sprinkling or providing other sources of water, extends markedly the limit of air temperature above the optimum which the animal can otherwise tolerate.
4. A hot environment produces a rapid rise in the respiration rate and a decrease in the pulse rate of non-sweating species of animals.
5. Increased air motion when the air temperature is below that of the animal surface temperature, or when the animal surface is kept wet, reduces the stressing as

indicated by a decrease in respiration rate and rectal temperature.

6. Thermal radiation from internal building surfaces because of difficulty of measurement and complexity of evaluation has not been well established.

ANALYSIS OF ENERGY EXCHANGE

Heat Transfer Relationship

The various forms of heat exchange between animals and their surround constitutes thermal environment. Therefore heat exchange differences by radiation, convection, conduction, and evaporation are presented as might be applicable to houses which are identical except for the covering material. A complete nomenclature of the terms used is given in Table 11.

Radiation exchange

An animal exchanges energy by radiation with its enclosure at a rate dependent upon the temperature of the animal's surface and of the enclosure, the emissivity of the animal and the enclosure, and the shape and size of the animal with regard to the enclosure. In general form the exchange of heat units per unit area can be written as

$$q = S\, F_a F_e (T_a^4 - T_{si}^4) \qquad (1)$$

where S is the Stephan-Boltzman radiation constant, F_a the factor relating the shapes of the animal and the enclosure, F_e the relationship between the emissivity e_a of the animal and e_s the emissivity of the enclosure, and T_a and T_{si} the absolute radiant temperatures of the animal and the enclosure respectively.

The exact rate, however, depends upon the evaluation of F_a and F_e. A body completely enclosed, which is true for a housed animal, has according to Hottel (14) a shape relationship of unity ($F_a = 1$). The F_e factor relating the emissivities of the animal and the house is written

$$F_e = \frac{1}{\frac{1}{e_a} + \frac{A_a}{A_s}\left(\frac{1}{e_s} - 1\right)} \qquad (2)$$

which includes the area A_s of the surfaces forming the enclosure and the area of the animal surface A_a.

If a body is small with respect to the enclosure, Hottel (14) gives

$$F_e = e_a \qquad (3)$$

If the body is large with respect to the enclosure (14):

$$F_e = \frac{1}{\frac{1}{e_a} + \frac{1}{e_s} - 1} \qquad (4)$$

For this thesis, an examination of F_e seems to be needed. Therefore, assume a body small compared to the enclosure.

$$Q_{a \rightarrow s} = S e_a T_a^{\,4} A_a \qquad (5)$$

Now raise the temperature of the body to T_s. Then

$$Q_{a \rightarrow s} - Q_{s \rightarrow a} = 0 \qquad (6)$$

The emission of the body at T_s is

$$Q_{a \rightarrow s} = Q_{s \rightarrow a} = S e_a T_{si}^{\,4} A_a \qquad (7)$$

and the net exchange is

$$Q_{net} = Q_{a \rightarrow s} - Q_{s \rightarrow a} = S e_a (T_a^{\,4} - T_{si}^{\,4}) A_a \qquad (8)$$

However the above neglects all reflection and reabsorption of energy. This assumption is valid when the body is extremely small with respect to its enclosure.

Now assume the $e_s = 0$ or that the enclosure is a perfect reflector.

$$Q_{net} = Se_a(T_a^4 - T_{si}^4)\ A_a = 0 \tag{9}$$

which can only be true if $T_{si}^4 = T_a^4$.

Since no net exchange can take place, T_{si} must represent the effective radiant temperature of the enclosure and is related to the actual temperature T_s as follows (26):

$$T_{si}^4 = T_a^4 + e_s(T_s^4 - T_a^4) \tag{10}$$

By substituting (10) in (8) the net exchange is written

$$Q_{net} = Se_ae_s(T_a^4 - T_s^4)\ A_a \tag{11}$$

which satisfies the latter requirements and can also be shown to represent the exchange between two parallel infinite planes for two reflections. If, in the latter case, all reflections are considered

$$Q_{net} = \frac{S(T_a^4 - T_s^4)A_a}{\frac{1}{e_a} + \frac{1}{e_s} - 1} \tag{12}$$

which also satisfies the conditions of (9).

For the intermediate case,

$$Q_{net} = \frac{S(T_a^4 - T_s^4)\ A_a}{\frac{1}{e_a} + \frac{A_a}{A_s}\ (\frac{1}{e_s} - 1)} \tag{13}$$

as $e_s \rightarrow 0$, $\frac{A_a}{A_s} \rightarrow 0$ if the emissivity of the enclosure is neglected.

Therefore, only for larger values of e_s accompanied by small values of $\frac{A_a}{A_s}$ may the emissivity of the enclosure be justifiably ignored.

For the case of two environments with the same shape and size relationship to the enclosed body, the difference in exchange, assuming the emissivity of the enclosure can be neglected, is

$$\begin{aligned} Q_{net} &= Se_a(T_1{}^4 - T_a{}^4)A_a - Se_a(T_2{}^4 - T_a{}^4)A_a \\ &= Se_a(T_1{}^4 - T_2{}^4)A_a \\ &= S(T_1{}^4 - T_2{}^4)A_a \qquad (14) \end{aligned}$$

If the emissivity of the enclosure is of influence and the enclosure is assumed to be a hemisphere resting on a flat plane

$$\begin{aligned} Q_{net} &= SA_a e_1(T_1{}^4 - T_a{}^4) - SA_a e_2(T_2{}^4 - T_a{}^4) \\ &= SA_a\left[T_a{}^4(e_2 - e_1) + (e_1T_1{}^4 - e_2T_2{}^4)\right] \qquad (15) \end{aligned}$$

In both of the above e_a and e_p, the emissivities of the animal and of the plane, are unity and subscripts 1 and 2 refer to hemispheres with emissivities e_1 and e_2 respectively.

Equation (11) represents the exchange between animal and enclosure, and equations (14) and (15) the difference in exchange caused by changing emissivity and temperature of the enclosure where emissivity does not and does affect exchange respectively.

Convection and Conduction

McAdams (20) relates transfer of heat by natural convection as

$$Q_c = KA_a(t_a - t_{air})^{1.25} \qquad (16)$$

where the coefficient K depends on surface characteristics and has values, $0.15 < K < 0.55$, for velocities below 50 feet per minute. Since air velocities reported in this thesis are quite low, this equation should apply.

If now the conditions of identical shape in two different environments are assumed, the difference in exchange in two different environments may be written as:

$$Q_{c2} - Q_{c1} = Q_{net} = (t_a - t_{air})_2^{1.25} - (t_a - t_{air})_1^{1.25} \qquad (17)$$

Kelly and associates (16) found a linear relationship between animal surface temperature, t_a, and air temperature, t_{air}, in a uniform environment, which for light hogs is

$$t_a = 71.8 + 0.31\ t_{air} \qquad (18)$$

Substitution of (18) in (17) and assumption of an average value for K,

$$Q_{net} = 0.33A_a\left[(71.8 - 0.69t_{air})_2^{1.25} - (71.8 - 0.69t_{air})_1^{1.25}\right] \qquad (19)$$

which represents the difference in exchange by convection and conduction between the animal and the environment due to different animal surface and air temperatures. Kelly and associates also found that K varied apparently with the respiration rate of the animal, and their data indicate that equation (19) representing losses by convection with normal air velocities in the chamber of 20 to 30 feet per minute should take the form

$$Q_{net} = 0.68A_s \left[(t_{air})_2 - (t_{air})_1 \right] \quad (20)$$

for heavy pigs in environments between 60°F. and 100°F.

<u>Evaporation</u>

In the case of the non-sweating animal, heat loss by evaporation is affected by the respiration rate and the relative humidity. An animal regulates to a certain extent the air intake to the lungs and subsequently the vapor loss from the lungs. Therefore, it may not be valid to assume the moisture evaporated to be directly proportional to the respiration rate. It appears to be valid to assume, however, that the respired air from the lungs is saturated and at a temperature approximately that of the internal body temperature, and that doubling the respiration rate doubles the muscular energy requirements of respiration. In general terms the evaporative heat loss is

$$Q = f(r, \Delta h) \quad (21)$$

where r is the respiration rate and Δh the enthalpy difference between the incoming and respired air.

For heat loss by evaporation, the net energy potential between two environments can be written

$$Q_{net} = (\Delta h_2 - \Delta h_1) r_w \quad (22)$$

where r_w is the respired weight of air in a given time and assumed here to be equal in both environments.

If it is assumed that the internal temperature of the animal remains constant, which is not true for hotter environments, equation (22) can be written simply as the difference in ambient air enthalpy,

$$Q_{net} = (h_2 - h_1)r_w \qquad (23)$$

In a stressed condition, a non-sweating animal will wet its body surface with liquids from the floor or from watering equipment. However, the general form of equation (23) still holds for identical shapes and air motion as

$$Q_{net} = (h_2 - h_1)W \qquad (24)$$

where W represents the weight of air in a given time passing over the body surface.

Summary of Potential Heat Loss by Change of Environment

The foregoing analyses have presented equations to express the differences in potential for environmental comfort between two buildings of identical shape and housing similar animals, but having covering materials with different thermal properties. These equations thus give a method for predicting the effect of environment on growth and feed consumption rates. By combination of these equations, the overall net potential with wet floors is

$$Q_{net} = Se_a(T_2^4 - T_1^4)A_a + 0.68\left[(t_{air})_2 - (t_{air})_1\right]A_a + (h_2 - h_1)(r_w + W) \quad (25)$$

To use equation (25) the following measurements are required:

(1) e_1 and e_2 which can be determined by solving equation (10), where T_{si} is the average radiometer reading of the enclosure, T_a is the temperature of the radiometer cold junction, and T_s is the algebraic average of the surface, all in absolute units, or which can be determined by the ratio of the radiometer output of the material to that of a black body at the same temperature.

(2) The sum of the products of the surface temperature and the surface area of the enclosure which can be found by appropriately dividing the area into sections and attaching thermocouples to the sections.

(3) The average temperature of the air surrounding the animals which can be determined by thermocouples, and the area of the animal surface in square feet, which is obtained from the Brody-Comfort equation (7),

$$A_a = 0.634\, W^{0.633}$$

where W is the weight of the animal in pounds.

(4) The respective enthalpies of the environments which can be obtained by dry and wet bulb temperatures.

(5) The number of pounds of air which are respired and which move across the surface of the animal in a given time in the case of a wet floor or are respired only when the floor is dry. These values at the present must be estimated until methods of measurement can be developed.

Feed Consumption, Weight Gain, and Net Heat Exchange Potential

Although within a group of animals of similar hereditary characteristics feed conversion into weight gain is a complexity of environment and physiology, a relationship between feed efficiency and environment should be apparent. Basically feeds may be cataloged as being comprised of energy levels, the proportions of each level dependent upon the particular feed. In equation form this is written

$$\text{Feed} = \text{TDN} + \text{Wastes} \qquad (26)$$

where TDN represents total digestible nutrients. A further breakdown can be written

$$\text{TDN} = \text{ME} + \text{Wastes} \qquad (27)$$

where ME is the metabolizable energy and in turn can be equated as

$$\text{ME} = \text{SDA} + \text{NE} \qquad (28)$$

where SDA is the specific dynamic action or heat increment of feeding, and NE the net energy or energy which is convertible to weight gain or muscular work.

If a condition of thermoneutrality is achieved, theoretically the heat loss to the environment is equal to the normal metabolic rate of heat production or basal metabolism plus any additional metabolism by virtue of movement, eating, etc., and without necessity of producing or losing additional heat for body temperature regulation. At this condition the NE requirement for body temperature regulation would be a minimum; or the SDA is approximately equal to the heat loss, for which purpose it is most efficient, and the NE is completely available for productive processes. Thus, the most ideal environment should be one which requires a heat loss equal to the SDA plus NE for normal activity with respect to the appetite of the animal. A hotter environment would then reduce appetite to lower heat production and possibly induce additional physical exertion requiring NE; a colder environment increasing appetite and also utilizing NE for temperature stabilization.

Since an animal requires some feed to carry on only the essential processes of living, if the feed consumption does not exceed this quantity, the feed efficiency approaches zero. On the other extreme, only so much feed can be handled efficiently by the digestive system and excess consumption results in a loss in feed efficiency.

Brody (3) relates the heat production in BTU per hour, Q, to the body weight in pounds, W, of mature homeothermic animals in a basal condition as

$$Q = 6.53\ W^{0.736} \qquad (29)$$

This equation (29) does not hold, however, for animals which are rapidly growing as in the case of swine from weaning to market weight of 225 pounds, the exponent being approximately unity up to puberty age or approximately 7 months and then declining to an estimated value of 0.6.

Regardless of the exact relationship between the portion of feed required for maintenance and the basal heat production, any additional feed consumption above this point will require the loss of additional heat approximately equal to the SDA of the additional feed consumed, ΔF, either by physical or chemical activity or both, if the environment remains constant. Therefore, the difference in ability to lose heat to the environment with the same degree of activity should be equal to the difference in the SDA, or more broadly, proportional to the difference in feed consumption on a uniform diet, i.e.

$$Se_a\,(T_2^{\,4} - T_1^{\,4})A_a + 0.68\left[(t_{air})_2 - (t_{air})_1\right]A_a + (h_2 - h_1)(r_w + W) = b\,\Delta F \qquad (30)$$

where b represents the proportion of energy of the feed which is SDA.

Similarly, if the amount of stored net energy, or that energy available for weight gain, ΔG, can be related to the feed consumption as $c\Delta F$, so that

$$b\Delta F = c\Delta F = d\Delta G \tag{31}$$

Now the equation may be written as:

$$Se_a\,(T_2^4 - T_1^4)A_a + 0.68\left[(t_{air})_2 - (t_{air})_1\right]A_a + (h_2 - h_1)(r_w + W) = d\Delta G \tag{32}$$

where d relates the energy value of weight gain.

However, a difference in environment normally results in a change in activity. Therefore, the right hand term of equation (31) must be modified to include the increased activity required to produce or lose heat and

$$Se_a\,(T_2^4 - T_1^4)A_a + 0.68\left[(t_{air})_2 - (t_{air})_1\right]A_a + (h_2 - h_1)(r_w + W) = (d + p)\Delta G \tag{33}$$

introducing a variable term which is not quantitatively known or readily measured.

Another interpretation of equation (33) is that the ratio of feed consumption to weight gain is a function of the environment or that the difference in this ratio is a function of the difference in environment, viz:

$$\left(\frac{\Delta F}{\Delta G}\right)_{1,2} = f\left\{Se_a(T_2^4 - T_1^4)A_a + 0.68\left[(t_{air})_2 - (t_{air})_1\right]A_a + (h_2 - h_1)(r_w + W)\right\} \tag{34}$$

If the physical properties of materials covering two identically shaped and exposed buildings are such that convection and conduction rates are identical, a difference between their internal environments can only result from a difference in the emissive properties of their respective materials. Thus,

$$\left(\frac{\Delta F}{\Delta G}\right)_{1,2} = f_1(e_2 - e_1) \qquad (35)$$

a measure of overall effect easily found by determining feed consumption, weight gain, and the emissivity of the materials or alternatively their surface and apparent radiant temperatures (Equation 10).

Verification of the validity of the foregoing assumption can be obtained by comparing the conductivity coefficients of wood, steel, and aluminum which would indicate that steel and aluminum should, under identical external and internal heat sources, have the same operative temperature and wood consistently be either higher or lower. If, however, the emissive properties are combined with those of conductivity the order of operative temperature should be steel, wood, and aluminum under summer conditions and wood, steel, aluminum in winter, and in order of highest to lowest, which is the record of results during the tests of this experiment.

EXPERIMENTAL

Introduction

As stated earlier it was recognized that the number of uncontrolled variables would make it necessary to use a relatively large number of animals and replications. Cost of the experiment was considered regarding alternatives of repeating tests over a period of years with fewer animals and buildings or of using more animals and buildings with one test and consequently more labor, instrumentation, and management. The first was selected since it required use only of existing instruments, was better suited to existing facilities for management, permitted better control of the experiment, and could be more easily financed.

One of the prerequisites was to duplicate as nearly as possible the type of housing and management commonly used in hog production. Consequently four-pen houses of three commonly used covering materials with space for four 200-pound animals per pen were designed. The houses were identical in design with the exception of the covering materials, one being aluminum, the second galvanized steel, and the third wood with an asphalt shingle roof over tight sheathing. Because of the difference in the properties of the three materials, three different environments could be expected.

Statistical analysis indicated need for three replications of each house or nine animal units in all. Two additional units were included to serve as feed and bedding storage, and to act as guard units on either end supplying the end animal units with the same exposure as the intermediate.

Under test conditions, all animals were fed free choice with the same ration, had free access to water of essentially the same temperature at all times, and ventilation rates were maintained as uniform as possible in all buildings. Records of surface and air temperatures, relative humidity, and periodic radiometer surveys were kept of conditions inside the buildings; and of solar intensity, air temperature, wind velocity, and relative humidity outside the buildings. These latter were not to be used at the present time for critical analysis but were kept more to indicate the type of external conditions prevailing during the test.

One winter test and one summer test have been conducted, but emphasis is placed on the summer study as no apparent differences in animal growth occurred during the winter study. The summer study used two animals per pen since the farrowing did not produce enough animals of similar hereditary and breed characteristics to place four animals per pen throughout. When placed on test these animals averaged approximately 115 pounds each and were taken off test at an approximate average individual weight of 215 pounds. Animals under the winter study initially averaged approximately 45 pounds each and were taken off at approximately 155 pounds each. In the winter study four animals per pen were available.

Design of Houses and Equipment

To provide flexibility of study within the limits of nine houses and three materials, all houses were prefabricated in identically shaped panels and shipped to the site for assembly. Close building tolerances could thus be maintained and future interchange of panels between buildings made to provide several combinations of wall and roof covering arrangements if desirable. Concrete slabs with frame anchors were cast in place. Glued and gusseted rigid gable frames (Figure 1) were used, panels being attached to the frames by bolts. Figure 2 shows the completed buildings. Figure 3 shows the plan of and equipment in the houses used. No windows were incorporated and a single door served each house.

To assure that each house responded only to animal and covering material causes, it was necessary to design equipment and utilities which would exert equal influence in all houses. As lights were an extraneous source of heat, they were of equal size and controlled by masterswitching. Therefore, all lights in all houses were either simultaneously on or off.

Unequal ventilation could also upset efforts. To prevent this possibility, identical fans were installed in all units and a special housing fabricated. Fans ran continuously and by means of an adjustable slide (Figure 4), fans were set to exhaust, recirculate or any combination of recirculating and

Fig. 1. Rigid frame 4-pen experimental hog houses showing frames and prefabricated panel.

Fig. 2. Completed houses in a random arrangement.

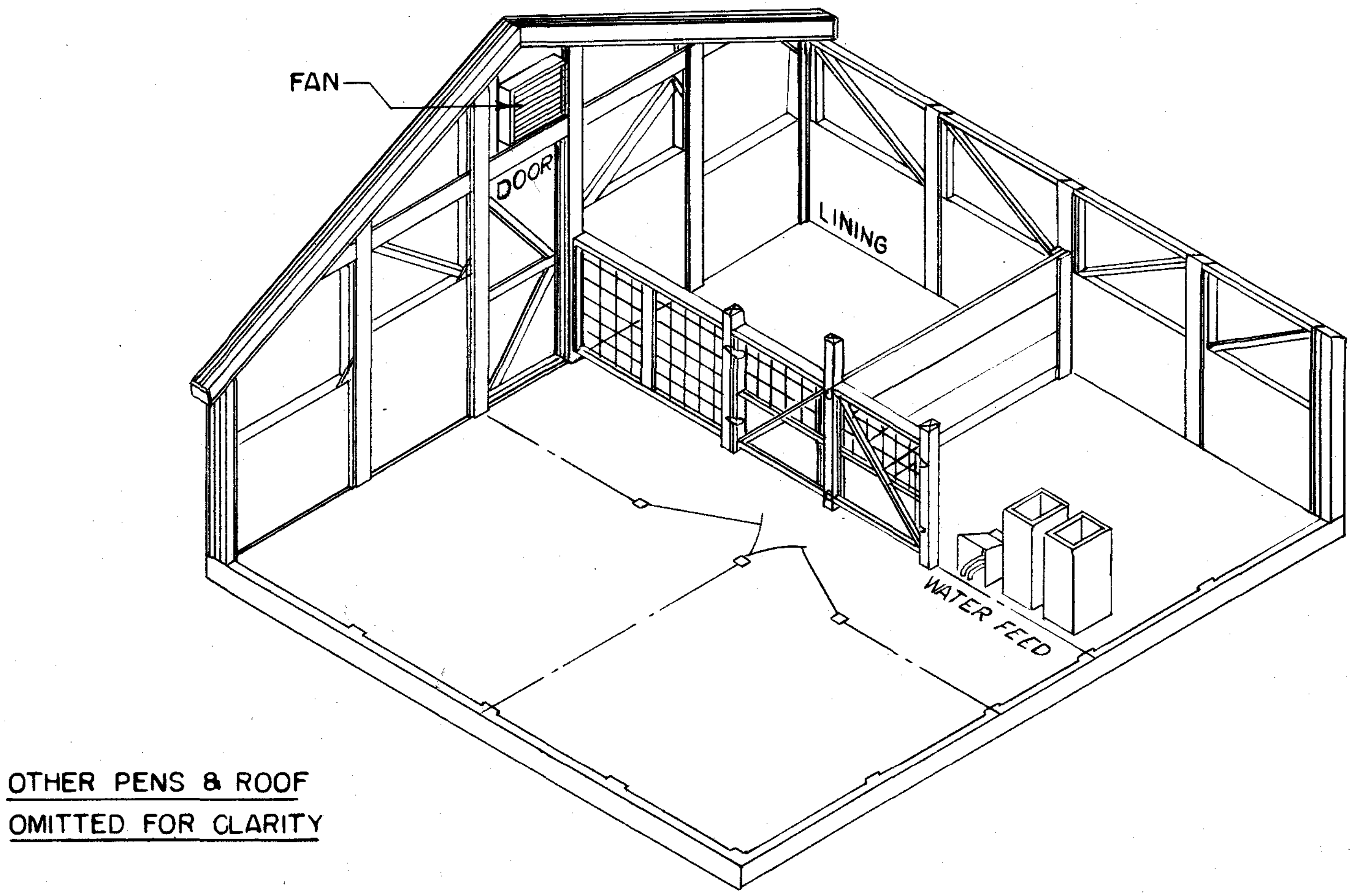


FIG. 3. LAYOUT OF 4-PEN 16 x 20 EXPERIMENTAL HOUSES.

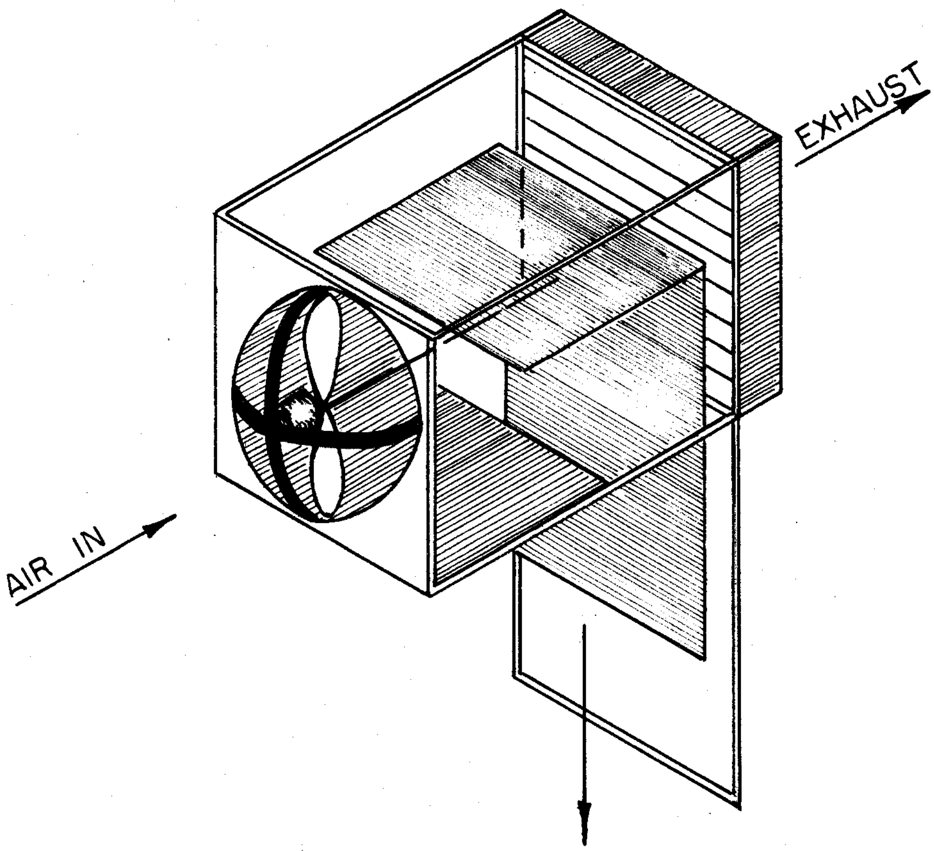


FIG. 4. VENTILATING FAN AND AIR CONTROL HOUSING WITH TOP AND SIDE REMOVED TO SHOW ADJUSTABLE DEFLECTOR.

exhausting. The chain operating the slide was color coded so that the same setting could be obtained in all houses. A chart (Figure 5) was prepared for setting ventilation on the basis of the outside air temperature and the average body weight of the animals under test. Fans were regulated therefore on the basis of anticipated moisture production.

No additional heating facilities were used in the study, but outlets were provided for heat lamps necessary during farrowing and the short period of time following farrowing when baby pigs occupy the houses.

Other tests in progress at the college on the effect of water temperature on the growth rate of swine showed signs that a specific range of water temperatures was optimum. It was also reasonable to expect that thermostatic control of the individual watering founts would present a different heat input rate among the houses. To eliminate this a special automatic watering fount (Figure 6) was designed which would give the same water temperature to all houses and thus eliminate both the effect of water temperature and the different rate of heat input. The principle of operation was to use ground temperatures for both a cooling source in summer and heating source in winter, recirculating the water through the system and connecting all founts in series. Tests were conducted on this unit prior to installation in the houses and the results were so favorable, one unit was installed in each pen for the water supply.

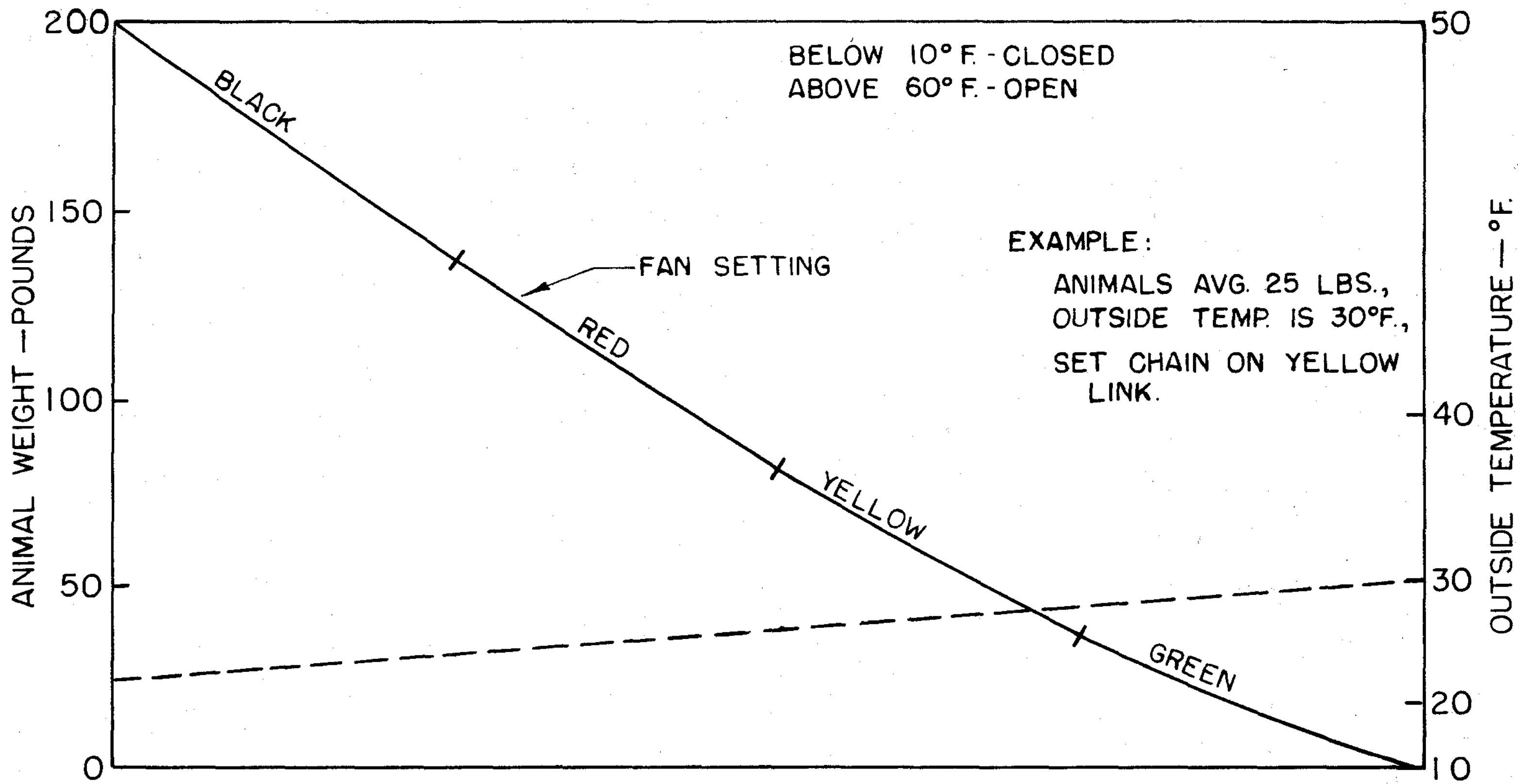
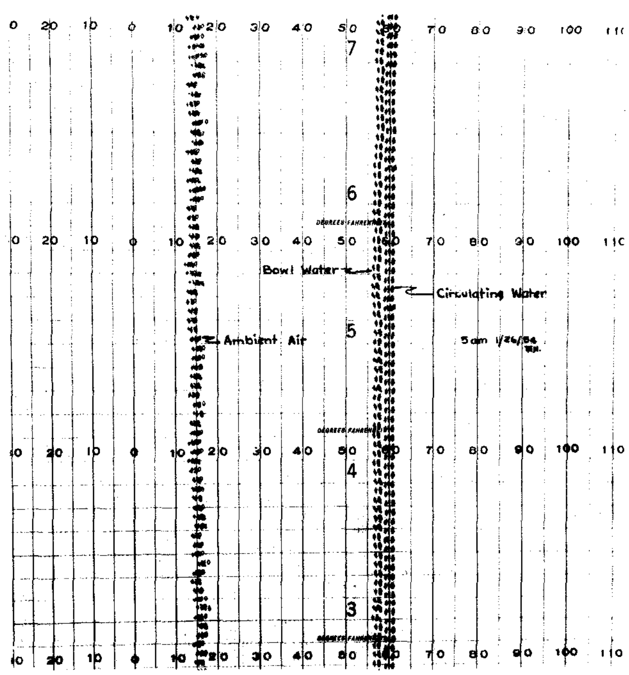


FIG. 5. NOMOGRAPH FOR DETERMINING EXHAUST FAN SETTING.

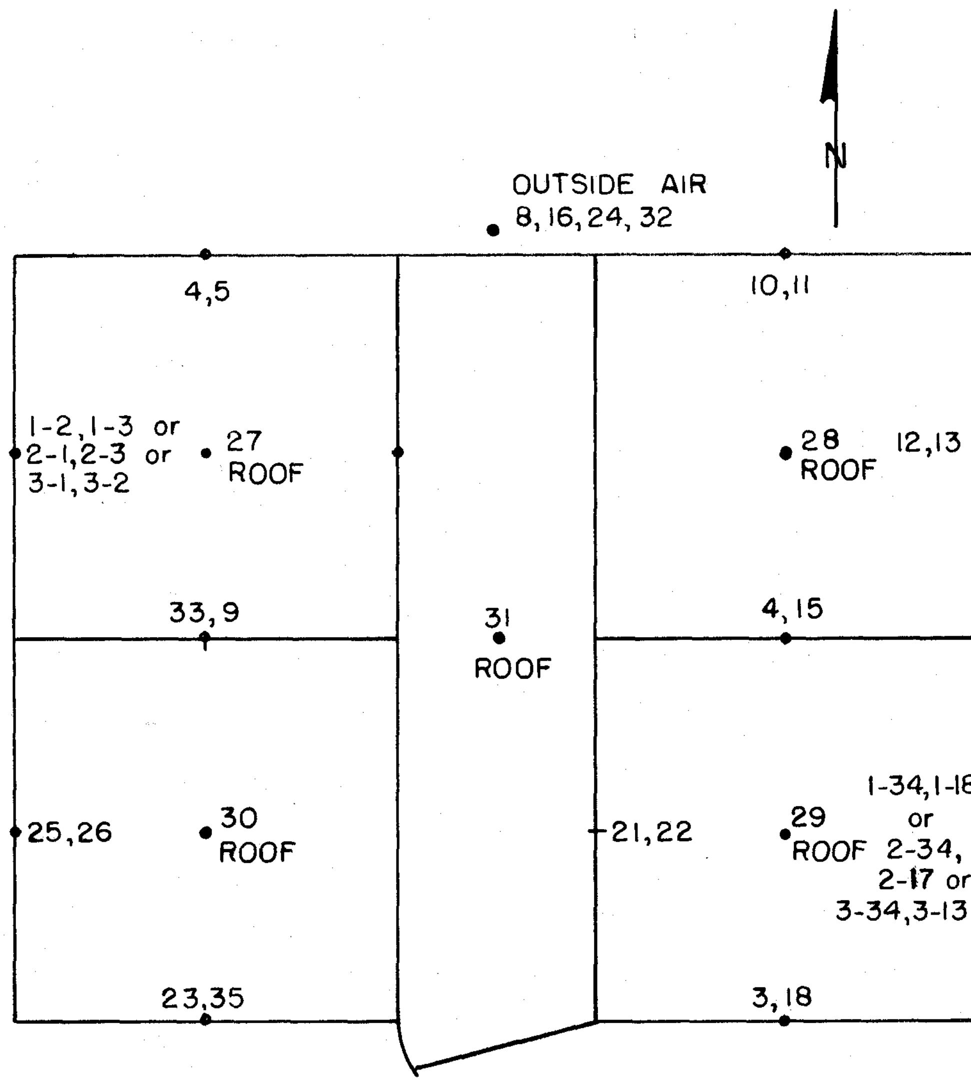
Fig. 6. Experimental hog waterer.


Bowl Water
Circulating Water
Ambient Air
5 am 1/26/84

Feeding equipment consisted of two commercial 200-pound capacity self-feeders in each pen. A monorail track was suspended from the framework of each house above the feeder locations. A portable scale and winch combination placed on the track enabled the feeders to be lifted and weighed in place and thus give a measure of feed consumed.

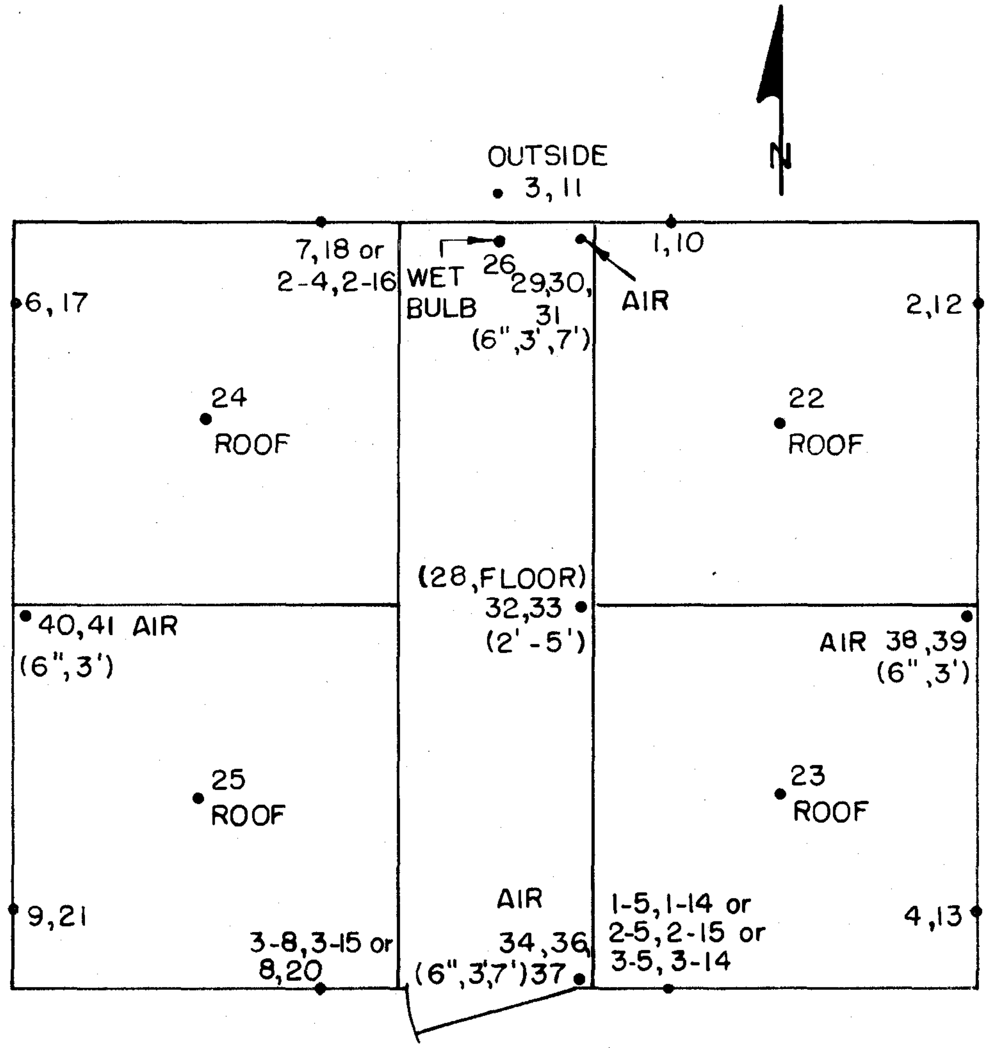
Instrumentation

Temperature measurements were made with copper-constantan thermocouples; with mercury bulb thermometers; and with hygro-thermographs. The majority of temperature readings were obtained from thermocouples mounted to the various surfaces and in the air, the other instruments used for checking such things as water temperature and general air temperature trends within the houses. In three of the houses, one of each type, an extensive installation of thermocouples was made and these couples fed through a common switching mechanism which automatically rotated among the three houses and permitted a single Brown 16 point recording potentiometer to record data from all three units. In the remaining six houses, thermocouples were placed only at check points and readings taken with a portable potentiometer at sufficient intervals to determine whether or not these houses were in agreement with the continuously recorded units. At the end of the summer study, changes in location of thermocouples (Figures 7,8) and improvements in the



NOTE: 1st NO. 6" ABOVE FLOOR - AIR TEMPERATURE
2nd NO. 30" ABOVE FLOOR - SURFACE TEMPERATURE
PREFIX INDICATES HOUSE NUMBER

FIG. 7 PLACEMENT OF THERMOCOUPLES — SUMMER 1955



NOTE: NUMBERS IN PARENTHESIS SHOW THERMOCOUPLE HEIGHT ABOVE FLOOR
THERMOCOUPLES NOT DESIGNATED ARE ON SURFACES

FIG. 8. PLACEMENT OF THERMOCOUPLES - WINTER 1955-56.

general setup were made, retaining the general principle for the winter study, and consequently fewer instrumentation difficulties were experienced.

Relative humidity records were obtained with weather bureau type hygrothermographs. Normally it required several days of periodic adjusting to obtain records which agreed with hand-aspirated psychrometer readings. Dust and other foreign materials in animal shelters also alter the reliability of these instruments, and they tend to lag and smooth out peaks during periods of rapid change in relative humidity. Therefore, an experimental wet bulb unit (Figure 9) which was being tested and developed by USDA Agricultural Engineers was modified to meet needs of this study, and three units installed for trial during the winter study. Response of these units appears quite good and the results of the winter trial warrants their continued use in future studies, although more study of this unit is needed before specific design recommendations can be made.

Radiant temperature readings of the interior surfaces of the units as well as surveys from a standard location inside the buildings were made periodically to find the emissivities of the surfaces and the comparative radiation intensity between buildings at the standard point. A radiometer survey stand to which was attached a Hardy dermal radiometer head were used for the surveys and the head detached for making surface emissivity measurements. The portable potentiometer used to obtain check temperature

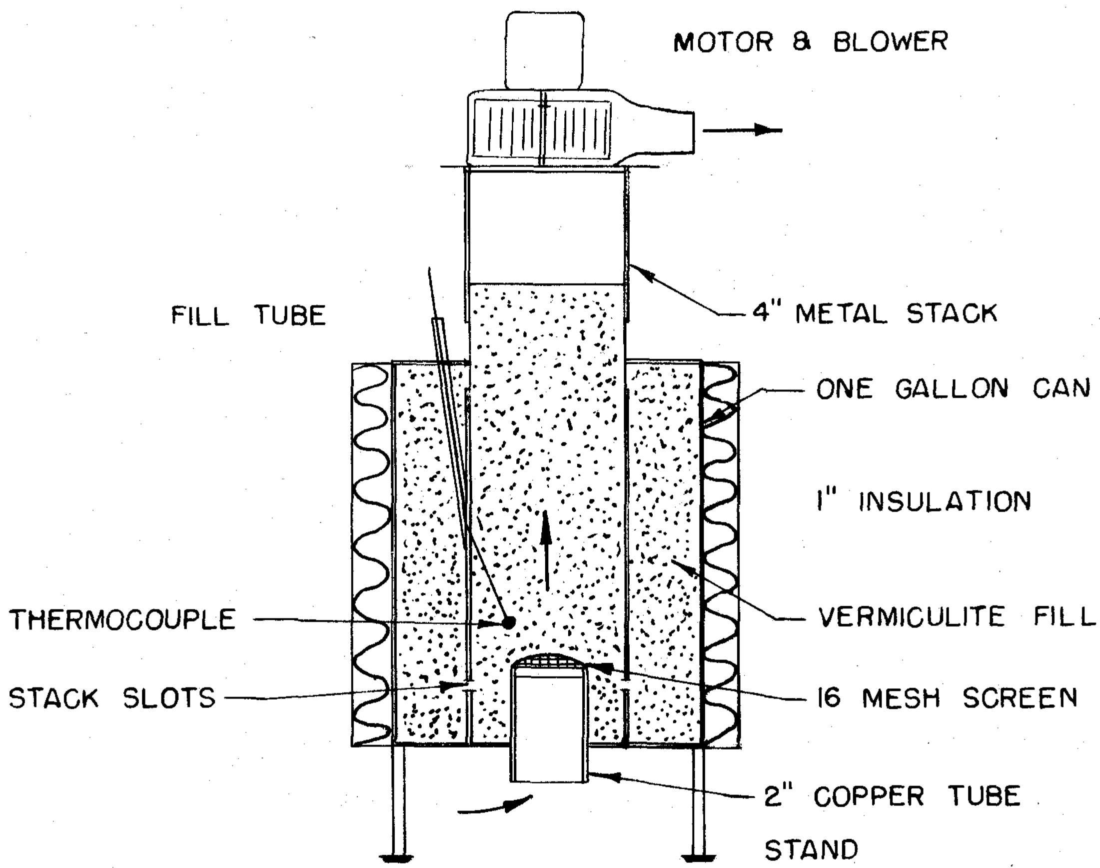


FIG. 9. EXPERIMENTAL WET BULB EQUIPMENT.

readings was equipped with a switching and reference block unit and the radiometer calibrated against controlled Leslie Cubes for use with this equipment.

During the summer study, wind velocities were recorded periodically with a windmill type anemometer. This system was abandoned at the end of the summer in favor of a recording system which was built to make use of a cup type anemometer and a circuit using a rectifier and a recording D.C. voltmeter. Internal air motion was checked with a vane type velometer, but readings were so low that the instrument sensitivity was insufficient to reliably differentiate between houses.

Solar intensities were recorded with an Eppley pyrheliometer connected to a Leeds and Northrup micromax.

Management

Animals were placed in the houses on three consecutive days, filling one of each type of house each day. At the end of the test animals were removed from the houses in the same order as they were put in. All feeders contained the same ration. Houses were cleaned daily during the summer study, but due to labor shortages, every other day cleaning was practiced during the winter, and it became apparent that daily cleaning was needed both winter and summer. No bedding was used during the summer, but a minimum of straw placed in the pens during the winter.

As heavy pigs should be more heavily stressed by hot weather and light pigs by cold weather, summer studies were scheduled for the heavy (100-200 pound) class and winter studies for the light (40-100 pound) class, the winter animals left under test past 100 pounds to give a tie with effect of colder environment on heavier pigs.

Body weights were measured every two weeks, animals being taken in groups to a nearby building with facilities for weighing. Feed consumption was determined on the same days as the animals were weighed by use of a portable winch scale which was carried from house to house. Future studies will attempt to take weekly measurements of weight gain and feed consumption as the bi-weekly method for these short periods makes application of statistical treatments more difficult.

Three-way crossbred pigs (Landrace-Duroc-Poland China) were used in both studies (Figures 10,11). Breed and hereditary differences could possibly account for some error in agreement of data. However, that error will not be known until more information is obtained.

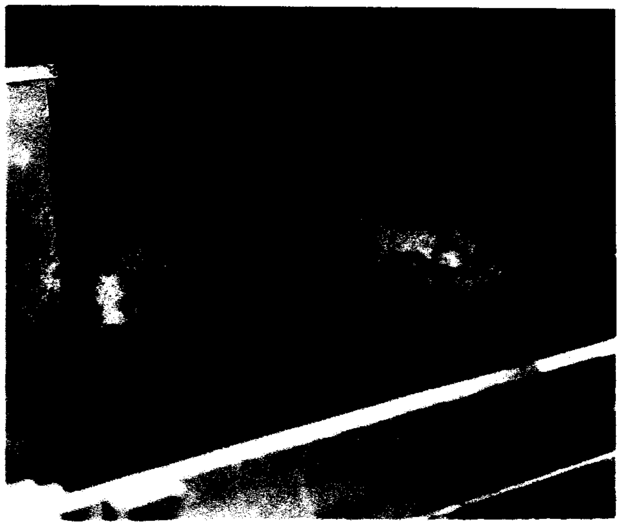
General Observations - Summer and Winter Study

Following are some general observations made in this study:

1. According to the local weather reports as broadcast by radio and reported in daily newspapers, the summer of 1955 during the early part of the test was cooler than normal for the area,

Fig. 10. Typical pigs used in summer study.

Fig. 11. Typical pigs used in winter study.



but during approximately the fourth week of the study rose above normal and continued in this fashion throughout the duration. The winter of 1955-56 was colder than normal, the lowest reading of -24°F. occurring in the early part of January, 1956. During the summer winds were light, normally ranging from three to eight miles per hour; during the winter winds on occasion were quite strong, one windstorm registering speeds as high as forty miles per hour.

2. Ammonia concentrations within the houses were much more detectable during the winter than during the summer which may have been due to every other day cleaning during the winter as compared to daily cleaning during the summer, or which may have seemed to be more objectionable because of less detectable pig odor.

3. Respiration rates of animals were observed periodically both summer and winter, but no difference between houses was apparent as pigs within a house would vary in respiration rate over a wide range. Respiration rates in the winter were normally 20 to 40 breaths per minute, whereas in the summer rates of from 60 to 180 were common. There was a noticeable relationship between the general range of air temperature and the respiration rate, the rate increasing rapidly when temperatures rose much above 85°F. At the higher temperatures there was also very little movement of the animals, although on occasion they roused to defecate or to splash water from the watering equipment over the

floor and their bodies. This presence of wet floors in the summer may have largely accounted for the higher than normal summer gains.

At night as the temperature began to fall, activity increased markedly, and throughout much of the night the animals moved about. As the houses had no windows, and lights were not turned on except for cleaning or other management operations, the pigs did not have a sharp contrast between day and night. From the weight gains, however, swine apparently eat and drink as well in the dark as they do in the light.

During the winter the animals were quite active, although in the early stages of the test there were signs of shivering from cold. However, no serious colds nor any loss of pigs occurred.

4. Drinking water temperatures during the summer test normally ranged between 70 and 75°F. and during the winter between 35 and 45°F.

5. There was a considerable manure accumulation on the lower surfaces of the building walls both summer and winter and heavy frost accumulation on the inside surfaces during the winter. Both of these items measurably influenced the emissivity of the surfaces concerned in the metal buildings, but did not noticeably change that of the wood.

Analysis of Summer Study

<u>Procedure for determining animal growth and inside temperatures</u>

The growth of animals by house type during the eight weeks of study is shown in Figure 12, the points plotted the average of the weights recorded at two week intervals and a curve fitted through these points. Averages for each of the nine houses are given in Table 1.

The average air temperature at 6 inches above floor level for each of the three types of houses as determined by thermocouples is shown for the same periods in Figure 13. Values were obtained by taking selected interval readings recorded throughout each day and night of each two-week period, weighting these temperatures by the number of hours the particular temperature prevailed, and then deriving the arithmetic mean for the two weeks.

Air temperatures were further broken down into two-week averages for the period between approximately sunrise and sunset (Figure 13), as the houses cooled to within 1 or 2°F. of one another shortly after sunset and began to separate shortly following sunrise. Therefore, if differences in the rate of growth could be related to differences in air temperature, the daytime average should more markedly describe the relationship. A 24-hour period during the summer test showing the trend of daily variations of temperatures within and between house types is illustrated in Figures 26,27 and 28 (p. 74,75,76).

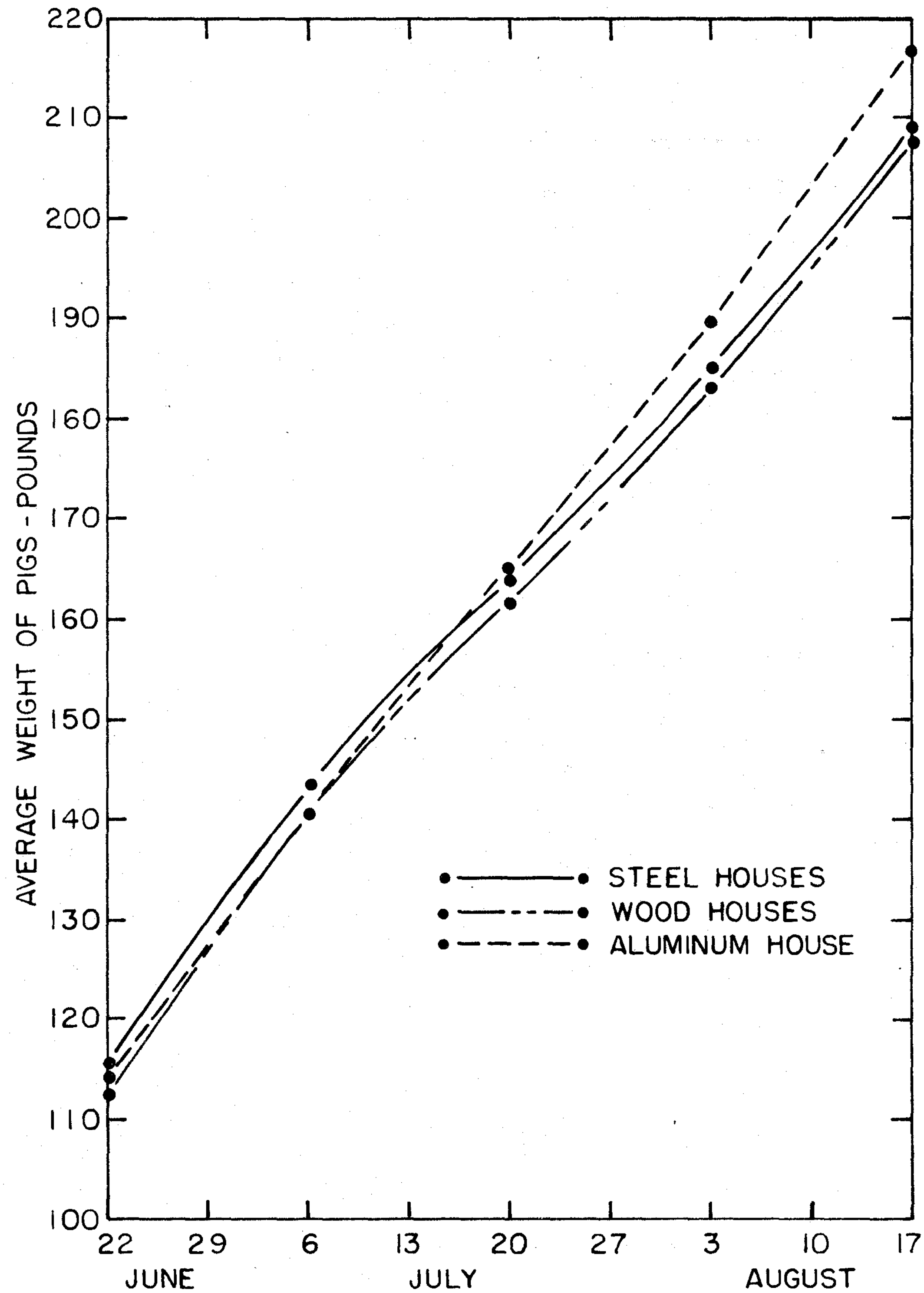


FIG. 12. WEIGHT GAIN OF SWINE - SUMMER 1955.

Table 1

Average Weights of Pigs by House
and 2 Week Period - Summer 1955

Rep. No.	House Type	Initial	2*	4	6	8
			Weeks on Test / Weight - Pounds			
1	Aluminum	115.5	150.6	176.4	203.4	232.0
	Steel	116.4	150.1	171.4	191.2	216.5
* 15 days	Wood	114.2	147.9	168.0	187.6	212.6
2	Aluminum	113.5	136.6	156.5	180.2	209.9
	Steel	117.0	139.2	162.5	184.1	207.0
* 14 days	Wood	114.5	143.0	164.6	188.6	211.1
3	Aluminum	113.2	136.0	159.2	182.2	209.0
	Steel	114.9	138.2	160.9	178.8	200.8
* 13 days	Wood	108.4	135.2	154.4	173.2	195.8

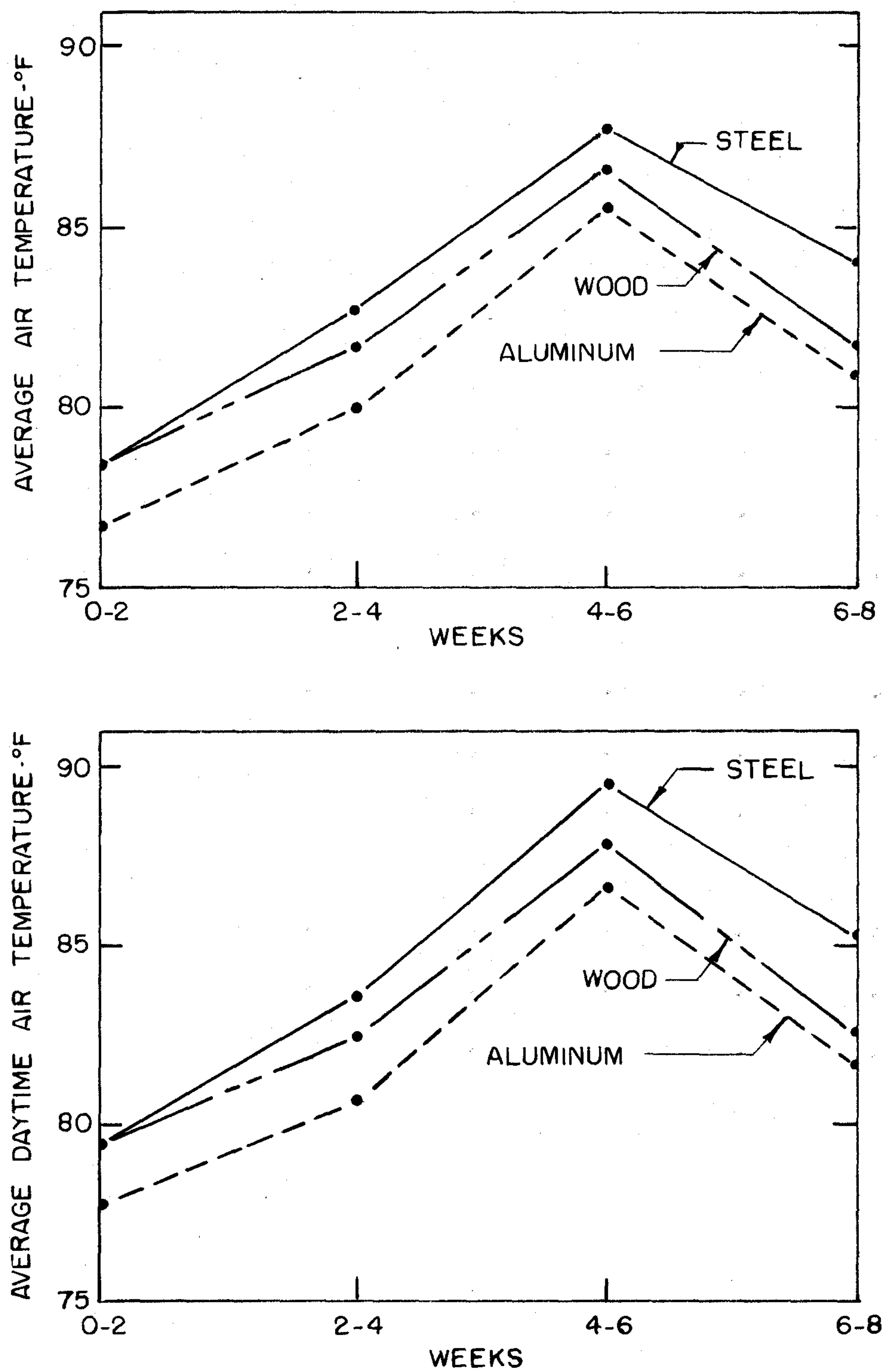


FIG. 13. AVERAGE AIR TEMPERATURE 6 INCHES ABOVE FLOOR BY HOUSE TYPES-SUMMER 1955.

A similar procedure was followed to obtain inside wall and roof surface temperatures (Figure 14), except the area of the surface as well as the time interval were used in weighting the values. These values were also transferred into absolute temperatures raised to the fourth power to compare as radiant temperatures.

Effective saturated air temperatures (Figure 15) were obtained from planimetered areas of the hygrothermograph charts for both relative humidity and air temperature and the average values of these measurements combined into the effective saturated temperature by use of equal enthalpy lines as shown in Figure 16. This method gives a uniform base to compare moisture content in three environments at different air temperatures and relative humidities.

Values for air temperatures as previously described, effective saturated temperature, roof and lower surface temperatures and outside air temperature by house type and two-week periods are given in Table 2.

Since six of the houses were not equipped with continuous recording equipment, the justification of using data from the one house of each type for the other two was assumed by comparing temperatures recorded at least once a day at check points in the other houses. With the exception of roof surface temperatures which could fluctuate as much as 10°F. within a very few minutes and make exact time comparisons extremely difficult, extreme

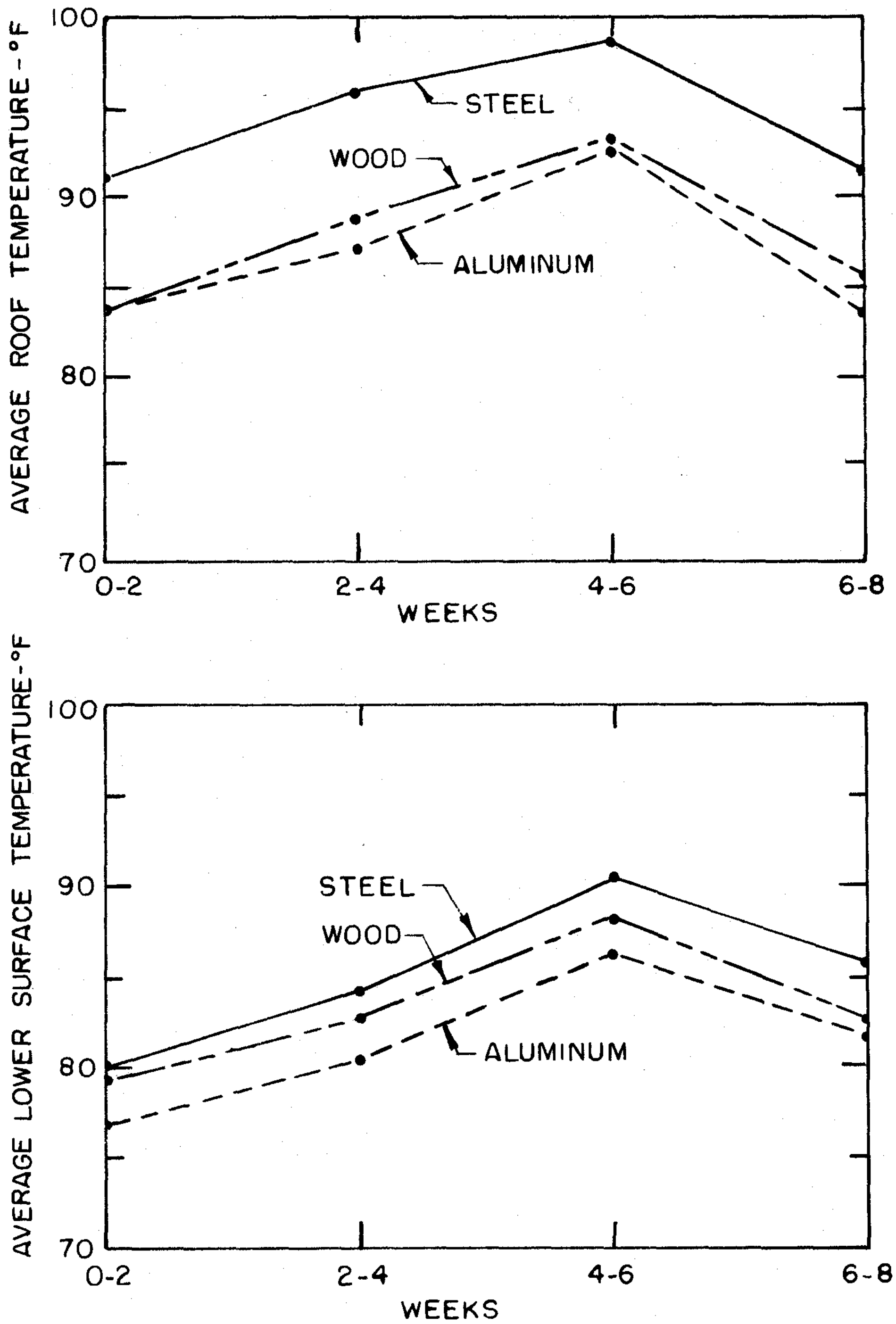


FIG. 14. AVERAGE ROOF TEMPERATURES AND LOWER SURFACE TEMPERATURES DAY PLUS NIGHT BY TWO-WEEK PERIODS - SUMMER 1955.

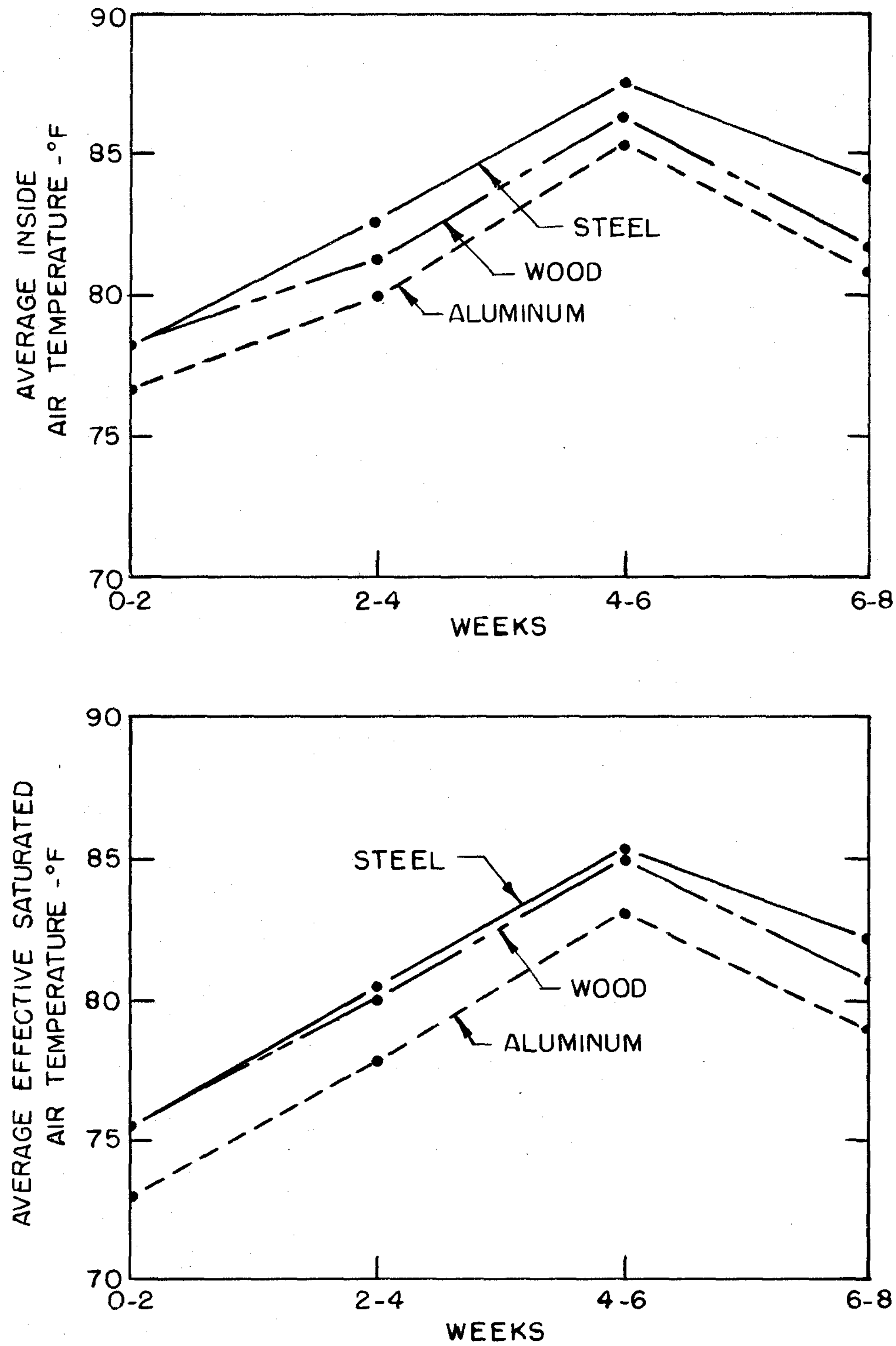


FIG. 15. AVERAGE INSIDE AIR TEMPERATURE AND EFFECTIVE SATURATED TEMPERATURE SUMMER – 1955.

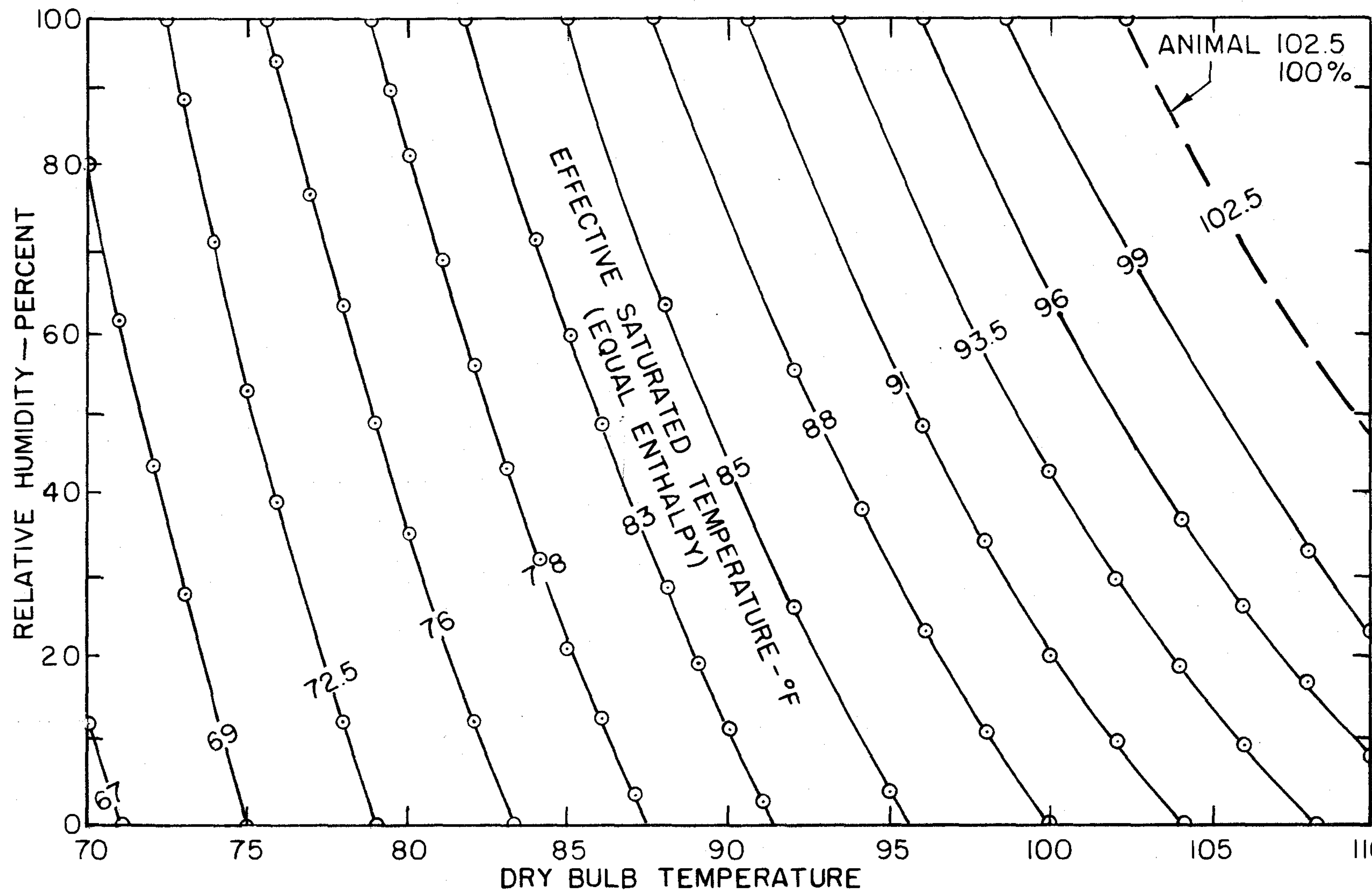


FIG. 16. EFFECTIVE SATURATED TEMPERATURES.

Table 2

Average Temperatures by Period and House Type - Summer 1955

Weeks Period	Day Plus Night				Daytime			Day Plus Night
	Air 6 in. Above Floor	Effective Saturated	Lower Surfaces	Roof	Air 6 in. Above Floor	Lower Surfaces	Roof	Outside
	Aluminum				Aluminum			
0-2	76.7	73.1	78.6	83.9	77.9	82.5	91.7	74.0
2-4	80.0	77.7	81.9	87.2	80.7	85.3	94.4	76.1
4-6	85.5	83.2	87.5	92.6	86.8	91.6	100.5	82.6
6-8	80.9	78.7	81.3	83.8	81.7	85.0	91.7	76.8
	Steel				Steel			
0-2	78.4	75.6	82.9	91.1	79.5	88.3	102.9	74.0
2-4	82.8	80.5	87.4	95.9	83.6	92.7	107.5	76.1
4-6	87.8	85.3	91.8	98.6	89.5	97.3	109.2	82.6
6-8	84.0	82.1	86.5	91.7	85.3	92.3	103.7	76.8
	Wood				Wood			
0-2	78.5	75.4	79.9	83.9	79.5	82.8	89.1	74.0
2-4	81.8	80.1	83.8	88.6	82.5	86.3	93.5	76.1
4-6	86.7	85.1	88.7	93.3	87.9	91.5	97.9	82.6
6-8	81.8	79.5	82.9	85.7	82.5	85.4	91.1	76.8

variations between readings in houses of a common type were within 2°F. of each other, an agreement which is within the expected experimental error.

Procedure for finding emissivity

The procedure for determining the average emissivity of the enclosure was to compare the radiometer reading of a surface with the temperature indicated by a thermocouple taped to that surface for several surfaces within each house and then solve for "e" in equation (10). However, it was found that the radiometer was apparently affected by convection currents as the reading of a surface at a known temperature with the radiometer pointed down was different from that obtained on the same surface with the radiometer pointing up. Also temperatures of building surfaces could fluctuate rapidly enough to cause variations in readings. Probably the most difficult problem was that of varying degrees of dust, manure, and moisture on the surfaces which can greatly alter the emissivity. As a result no consistent values of emissivity could be obtained. To acquire some indication, a period when the surface temperatures were very constant for a few hours was taken as representative, values obtained as reported in Tables 3 through 5, and the average of these values used for the emissivities.

In addition emissivity values for roofing samples of aluminum and galvanized steel were obtained between the temperatures of

Table 3

Determination of Average
Emissivity - Aluminum House

Couple No.	$\frac{T_w^4}{10^8}$	$\frac{T_{ref}^4}{10^8}$	$\frac{T_{w'}^4}{10^8}$	$\frac{T_{ref}^4-T_w^4}{10^8}$	$\frac{T_{ref}^4-T_{w'}^4}{10^8}$	$e=\frac{T_{ref}^4-T_w^4}{T_{ref}^4-T_{w'}^4}$
1	7.023	7.236	6.410	0.213	0.826	0.26
2	6.947	7.236	6.410	0.289	0.826	0.35
4	6.947	7.182	6.461	0.235	0.721	0.33
5	6.970	7.182	6.260	0.212	0.922	0.23
6	6.917	7.290	6.260	0.373	1.030	0.36
7	6.970	7.290	6.360	0.320	0.930	0.34
8	6.947	7.182	6.260	0.235	0.920	0.26
9	6.864	7.129	6.310	0.265	0.819	0.32
10	6.864	7.236	6.310	0.372	0.926	0.40
12	6.812	7.236	6.161	0.424	1.075	0.39
13	6.842	7.182	6.210	0.340	0.972	0.35
14	6.656	7.182	6.210	0.526	0.972	0.54
15	6.842	7.182	6.210	0.340	0.972	0.35
17	6.947	7.290	6.210	0.343	1.080	0.32
18	6.917	7.290	6.260	0.373	1.030	0.36
21	6.790	7.129	6.210	0.339	0.919	0.37
22	6.760	7.236	6.210	0.476	1.026	0.46
23	6.760	7.182	6.210	0.422	0.972	0.43
24	6.947	7.290	6.260	0.343	1.030	0.33
25	6.760	7.129	6.260	0.369	0.869	0.42
					avg =	0.36

Table 4

Determination of Average
Emissivity - Steel House

Couple No.	$\frac{T_w^4}{10^8}$	$\frac{T_{ref}^4}{10^8}$	$\frac{T_{w'}^4}{10^8}$	$\frac{T_{ref}^4 - T_w^4}{10^8}$	$\frac{T_{ref}^4 - T_{w'}^4}{10^8}$	$e = \frac{T_{ref}^4 - T_w^4}{T_{ref}^4 - T_{w'}^4}$
1	6.760	7.023	6.360	0.263	0.663	0.40
2	6.812	7.023	6.614	0.211	0.409	0.52
4	6.635	6.970	6.614	0.335	0.356	0.94
5	6.760	6.970	6.310	0.210	0.710	0.30
6	6.554	7.076	6.310	0.522	0.766	0.68
7	6.708	7.076	6.310	0.368	0.766	0.48
8	6.605	6.970	6.360	0.365	0.610	0.60
9	6.708	6.970	6.614	0.262	0.356	0.74
10	6.686	7.023	6.390	0.337	0.633	0.53
12	6.760	7.023	6.260	0.263	0.763	0.34
13	6.554	6.970	6.260	0.416	0.710	0.58
17	6.554	7.076	6.310	0.522	0.766	0.68
18	6.533	7.076	6.340	0.543	0.736	0.74
20	6.554	6.970	6.310	0.416	0.660	0.63
21	6.708	6.970	6.360	0.262	0.610	0.43
22	6.554	7.023	6.360	0.469	0.663	0.71
23	6.431	6.970	6.360	0.539	0.610	0.88
24	6.656	7.076	6.360	0.420	0.716	0.59
25	6.656	6.970	6.460	0.314	0.510	0.62
					avg =	0.60

Table 5

Determination of Average Emissivity - Wood House

Couple No.	$\frac{T_w^4}{10^8}$	$\frac{T_{ref}^4}{10^8}$	$\frac{T_{w'}^4}{10^8}$	$\frac{T_{ref}^4 - T_w^4}{10^8}$	$\frac{T_{ref}^4 - T_{w'}^4}{10^8}$	$e = \frac{T_{ref}^4 - T_w^4}{T_{ref}^4 - T_{w'}^4}$
1	6.482	6.917	6.512	0.435	0.405	1.07
2	6.482	6.917	6.360	0.435	0.557	0.78
4	6.452	6.864	6.360	0.412	0.504	0.82
5	6.605	6.864	6.461	0.259	0.403	0.64
6	6.790	6.917	6.768	0.127	0.149	0.85
7	6.605	6.917	6.563	0.312	0.354	0.88
8	6.554	6.812	6.461	0.258	0.351	0.73
9	6.738	6.812	6.716	0.074	0.096	0.77
10	6.452	6.917	6.312	0.465	0.605	0.77
12	6.452	6.917	6.260	0.455	0.657	0.69
13	6.452	6.864	6.260	0.412	0.604	0.68
15	6.452	6.864	6.360	0.412	0.504	0.82
16	6.605	6.917	6.461	0.312	0.456	0.68
17	6.452	6.917	6.310	0.465	0.607	0.77
20	6.452	6.812	6.360	0.360	0.452	0.80
21	6.584	6.812	6.410	0.228	0.402	0.57
22	6.482	6.917	6.360	0.435	0.557	0.78
23	6.452	6.864	6.360	0.412	0.504	0.82
24	6.584	6.917	6.410	0.333	0.507	0.66
25	6.503	6.812	6.430	0.309	0.382	0.81
					avg =	0.77

$50^{\circ}F.$ and $150^{\circ}F.$ by removing the side of a Leslie Cube and inserting the sample (Figure 17). These tests were made in a controlled temperature room, the emissivity computed by dividing the radiometer output when reading the sample by that obtained from the re-entrant cone, both surfaces held at constant temperature by the stirred water bath. The samples were then allowed to weather and the emissivity determinations repeated at intervals. Very consistent results (Figure 19) were obtained under these controlled conditions. However, the effect of dust was demonstrated when extremely dirty samples were tested. Values thus obtained were quite high on new samples, being approximately 0.8 - 0.9 for both steel and aluminum sheets but dropping down to 0.10 - 0.20 on rinsing the samples in clear water and allowing to dry.

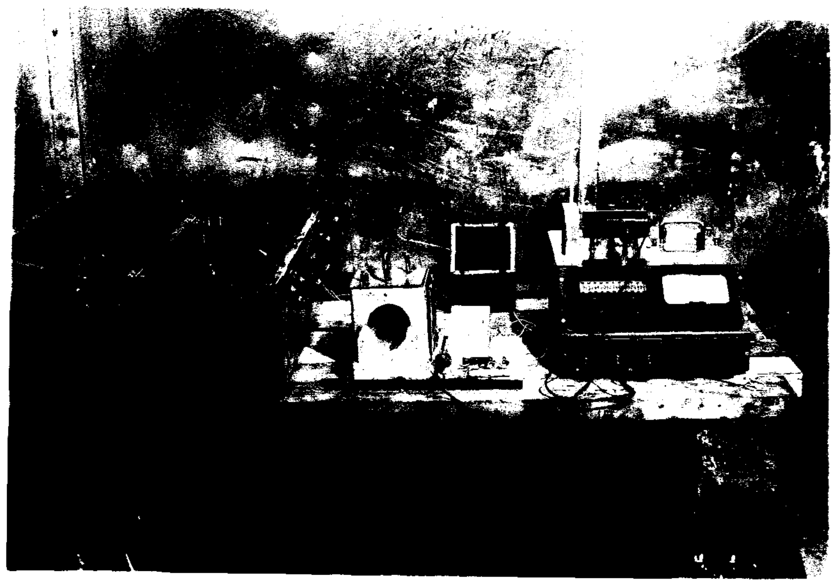
As the radiometer was to be used under uncontrolled conditions, a calibration curve of the unit used was made by measuring the output of the radiometer when "seeing" the re-entrant cone of a Leslie Cube against the temperature of the cube for several levels of cube temperature and room temperature. This curve was then used to determine the response of the radiometer when used under the various field conditions, and a sample appears in the Appendix.

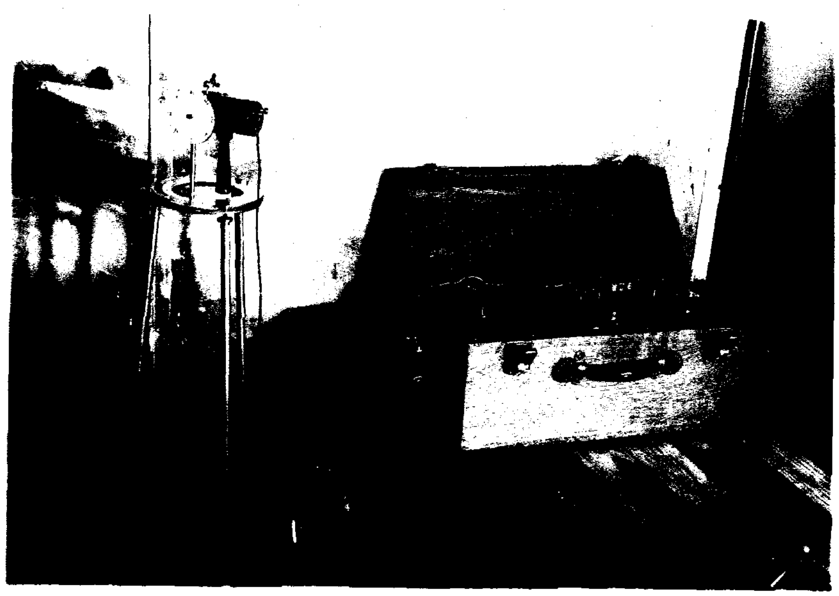
<u>Procedure for making radiometer survey</u>

A survey stand (Figure 18) was constructed which would

Fig. 17. Equipment used for finding emissivities of metal roofing samples.

Fig. 18. Radiometer survey stand, radiometer, and potentiometer.





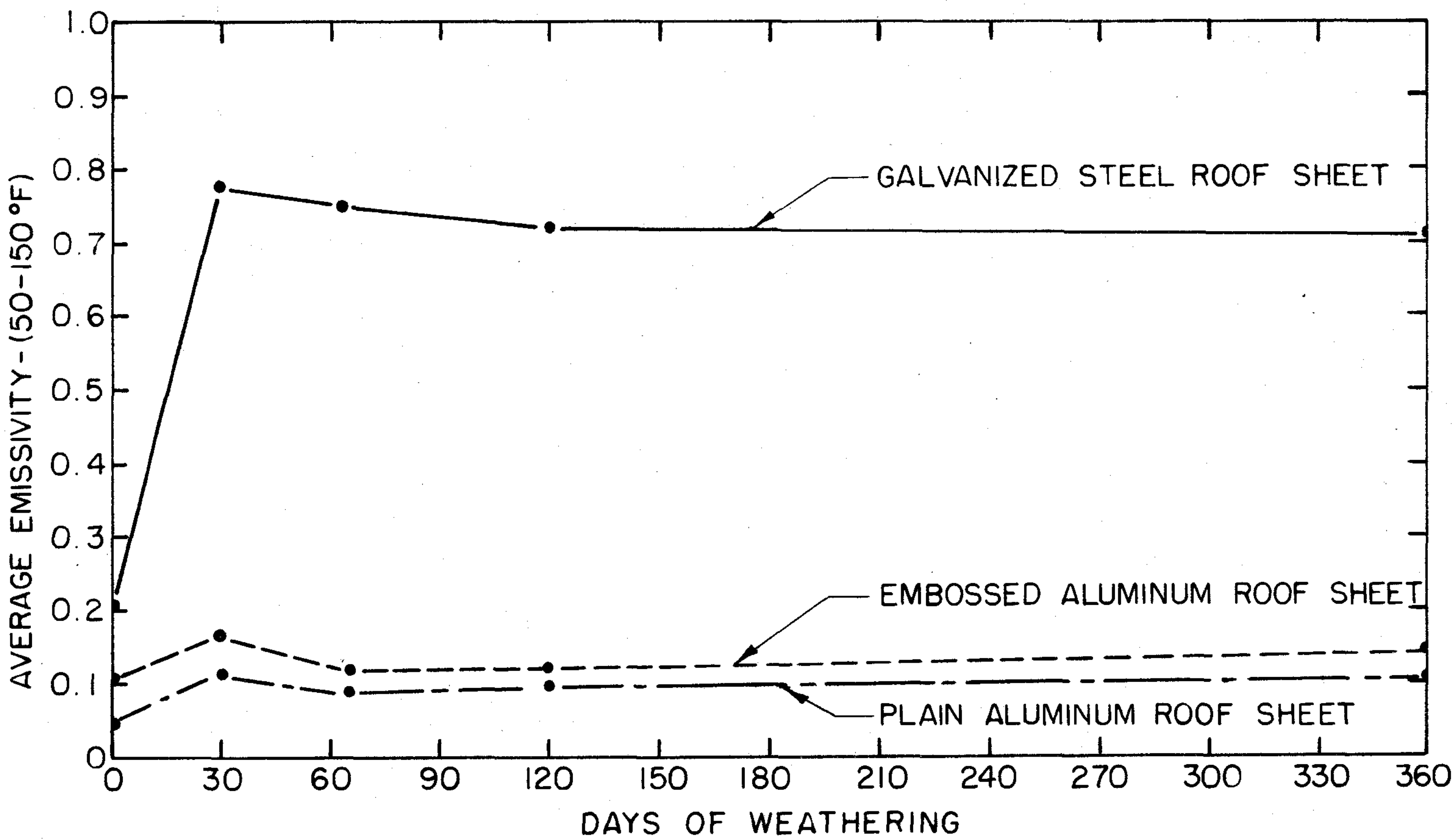


FIG. 19. RESULTS OF LABORATORY STUDIES OF EMISSIVITY OF NEW AND WEATHERED ROOFING SAMPLES.

receive the radiometer head and provide a means of orienting and obtaining consistent surveys of the enclosure as outlined by Stoll and Hardy (26). By taking the average of readings from observations spaced 45° both horizontally and vertically, describing a complete sphere, a fictitious equivalent black body temperature is obtained, this temperature being the same as theoretically would be obtained in a black enclosure uniformly at that temperature. The true temperature of the enclosure can also be obtained from equation (10) providing the emissivity of the enclosure is known. As the equivalent black body temperature thus found depends on both the temperature of the enclosure and of the radiometer cold junction, its value will change with a change in the temperature and shape of the observing body. However, the survey does give a comparison of radiant intensities otherwise difficult to obtain in an enclosure of numerous temperature sources and emissivities, and averages of several surveys taken during the study showing the relationship between the house types are presented in Table 6.

<u>Air temperature and feed efficiency</u>

The correlation between the pounds of feed consumed per pound of weight gain and the inside air temperature at 6 inches above the floor is shown in Figure 20. The equation for the line fitted by the least squares method and the correlation coefficient are also given. Values for weight gain and feed consumption are

Table 6

Samples of Equivalent Radiant Temperature by Radiometer Surveys from 3 Feet Above Floor in Center of House - Summer 1955

Date	Time	House Type	$t_{ref.}$ °F	Avg. Reading Millivolts	t_{ERT} °F
		Aluminum		-0.05	98.0
7-22	3-3:30 pm	Steel	100	0.14	105.5
		Wood		0.09	103.7
		Aluminum		0.00	91.0
7-23	10-10:30 am	Steel	91	0.11	95.3
		Wood		0.10	95.0
		Aluminum		-0.01	89.5
8-5	3:30-4 pm	Steel	90	0.16	96.3
		Wood		0.12	94.5
		Aluminum		0.04	94.7
8-12	3-3:30 pm	Steel	93	0.30	105.0
		Wood		0.12	97.5
		Aluminum	87	0.04	88.5
8-19	10:30-11 am	Steel	88	0.29	99.5
		Wood	85	0.15	91.0

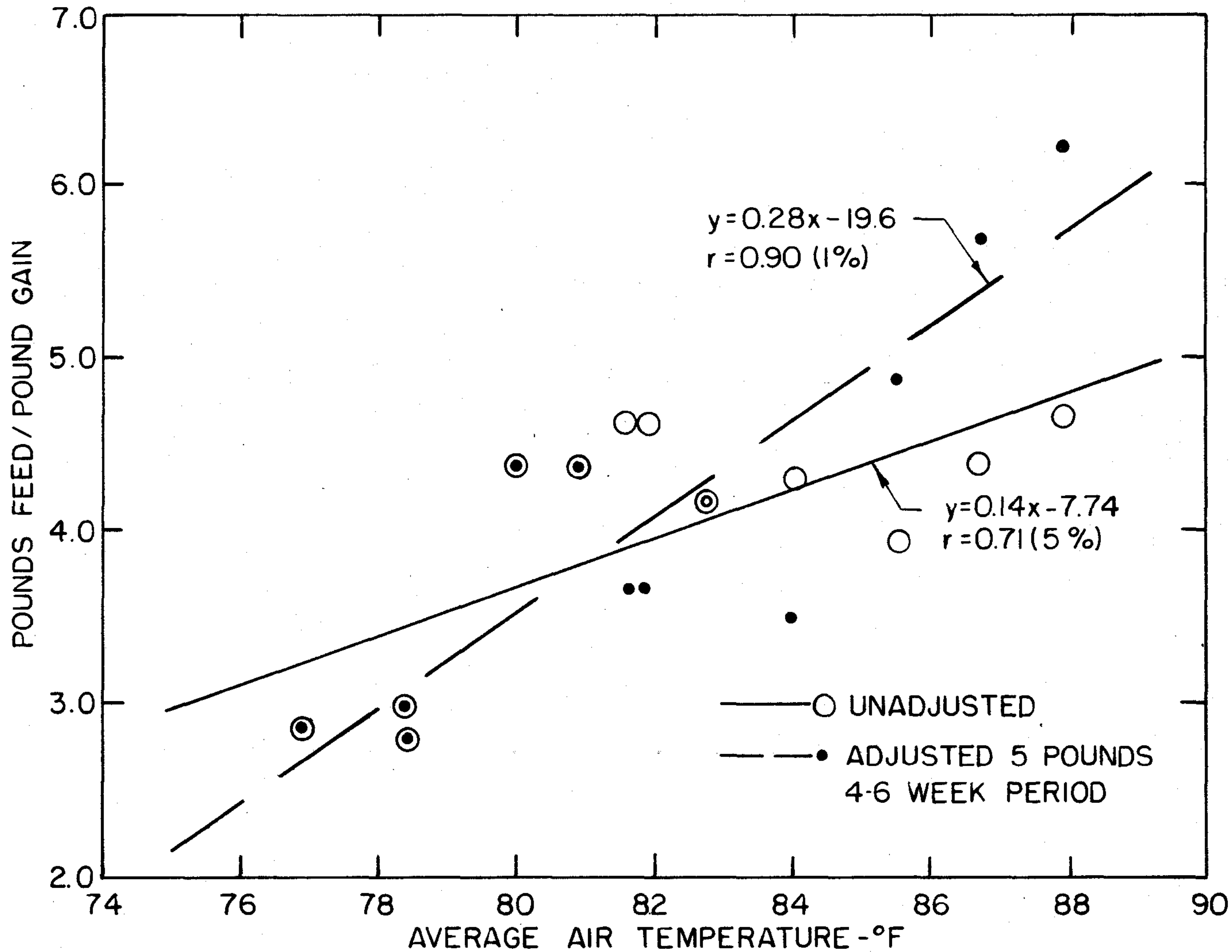


FIG. 20. INSIDE AVERAGE AIR TEMPERATURE VERSUS FEED EFFICIENCY AVERAGE OF ALL HOUSES BY TWO-WEEK PERIODS - SUMMER 1955.

presented in Table 7. Inspection of average weight gains and actual feed consumed by the animals strongly indicates an error in the third two week interval as the animals in two of the house types show an increase in efficiency over the previous cooler period. This phenomena is contrary to the remainder of the data and to tests under controlled environment (13). Study of the environment records was made to see if a sudden cool cycle, which could encourage a spurt in gain, or a brief hot spell just prior to the previous weight period, causing a temporary slack at that time, might be responsible. No such evidence was found. The possibilities of a feed or animal weight error caused perhaps by scales not in balance, accumulation of feces, or similar inaccuracies were examined. Again there was no definite evidence, although records indicate one group of eight pigs gained 48 pounds more than during the previous periods on 60 pounds less of feed; another, 19 pounds more gain on 81 pounds less of feed; ratios which are on the order of 10 percent more gain on 10 percent less feed.

An arbitrary error of 5 pounds excess in animal weights was assumed for this period and this 5 pounds added to the next period. A comparison of plots is shown in Figures 22 and 23. A 3-pound adjustment also causes a reverse in the slope of the feed efficiency curve between periods two and three. These curves indicate that even a few hours difference in weighing animals can radically alter the apparent feed efficiency during a two week

Table 7

Weight Gain and Feed Consumption of Pigs by House and 2 Week Period - Summer 1955

Rep. No.	House Type	0 - 2* Weight Gain Pounds	0 - 2* Feed Pounds	2 - 4 Weight Gain Pounds	2 - 4 Feed Pounds	4 - 6 Weight Gain Pounds	4 - 6 Feed Pounds	6 - 8 Weight Gain Pounds	6 - 8 Feed Pounds
	Aluminum	281	777	206	908	216	848	229	1021
1	Steel	270	745	160	774	159	759	202	851
* 15 days	Wood	269	739	161	757	157	714	200	833
	Aluminum	197	555	157	727	210	752	197	851
2	Steel	178	584	186	738	173	729	183	791
* 14 days	Wood	228	667	173	803	192	722	180	856
	Aluminum	182	531	186	784	184	782	214	929
3	Steel	187	590	181	738	143	725	176	770
* 13 days	Wood	215	583	153	705	151	735	180	802

period considering that each animal may be eating as much as 8 pounds of feed per day.

Air temperature and average daily gain

Feed efficiency does not represent growth rate. Therefore both adjusted and unadjusted correlations of average daily gain with air temperature are shown in Figure 21. The relationship between air temperature at the 6 inch level and the average daily gain by house type for each two week interval is included in Figure 22.

Again if an arbitrary correction of 5 pounds in the third period weights is applied, the effect on daily weight gain is shown in Figure 23.

Effective saturated temperature, surface temperatures, and feed efficiency

Plots of average effective saturated temperature and average surface temperature using the aluminum house as an example. (Figure 24) shows the same curve shape as that of average inside air temperature. This would indicate that the inside air temperature is an equally effective criterion to judge environment-feed efficiency relationships in a naturally varying situation. However, difficulty is encountered on attempts to separate the individual effects on the animals which might be associated with radiation exchange or relative humidity, as the inside air is not independent of these other factors as would be the case in a calorimeter where conditions are artificially induced.

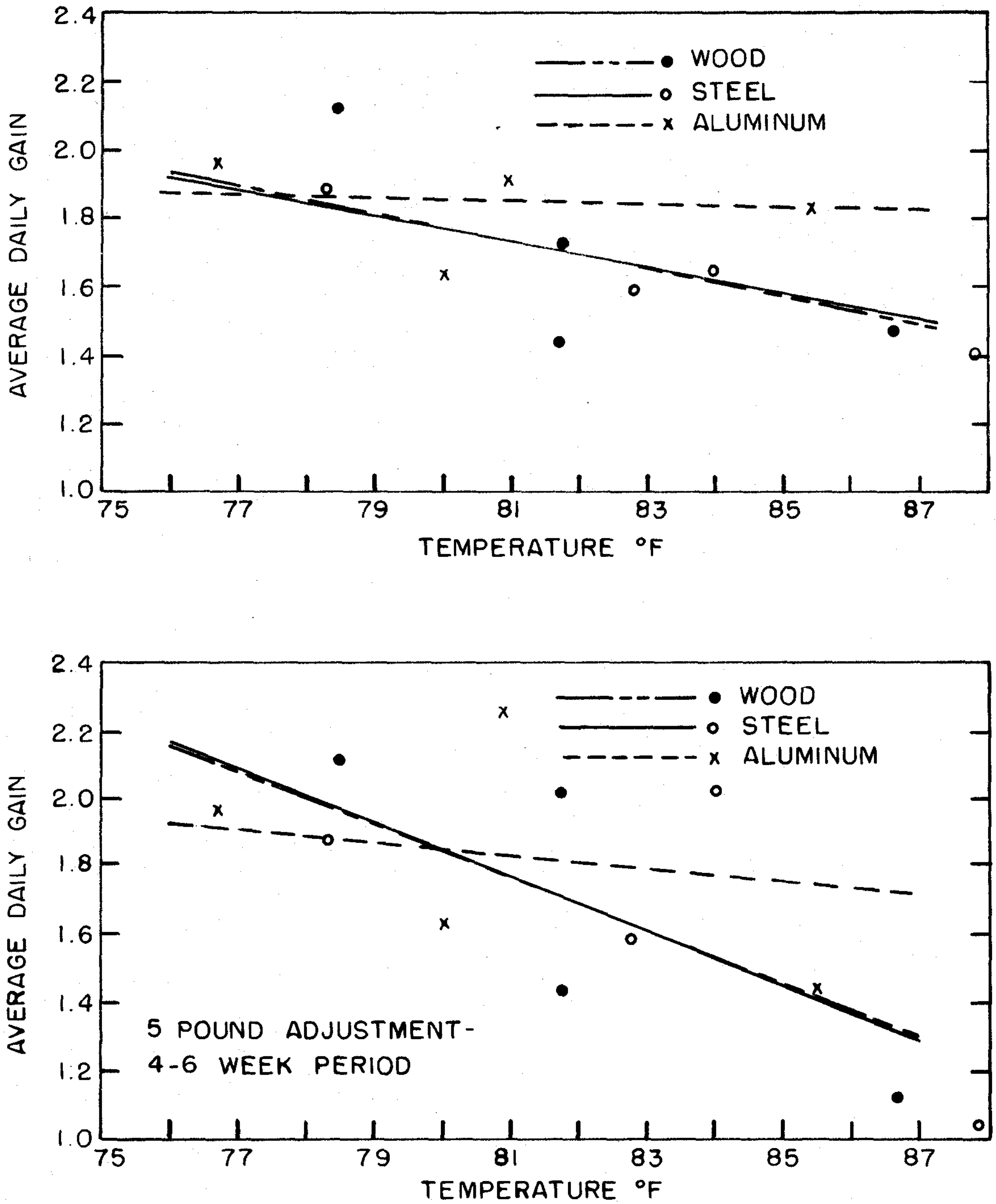


FIG. 21. INSIDE AVERAGE AIR TEMPERATURE VERSUS AVERAGE DAILY GAIN BY HOUSE TYPE — SUMMER 1955.

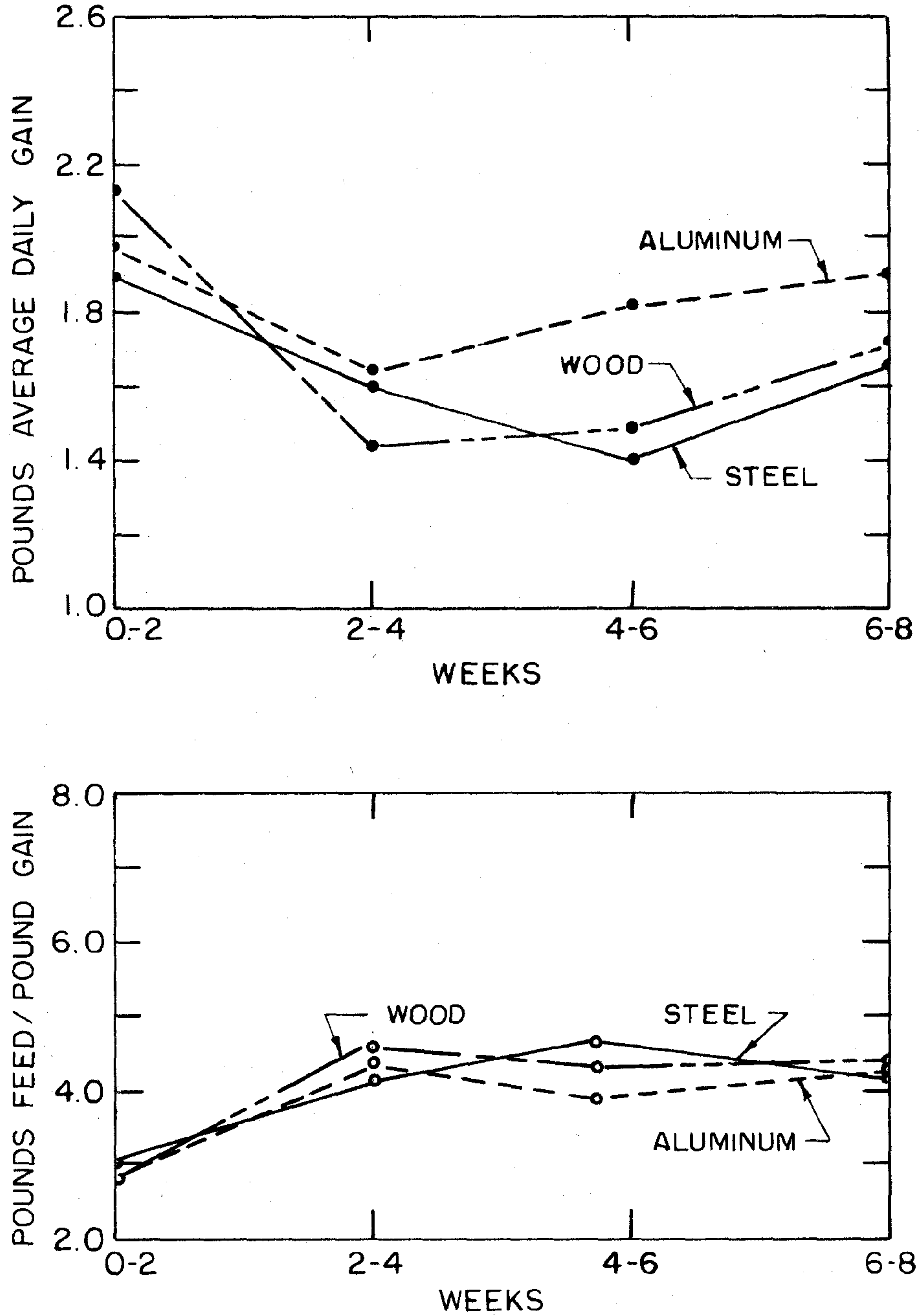


FIG. 22. AVERAGE FEED EFFICIENCY AND AVERAGE DAILY GAIN OF SWINE BY HOUSE TYPE - SUMMER 1955.

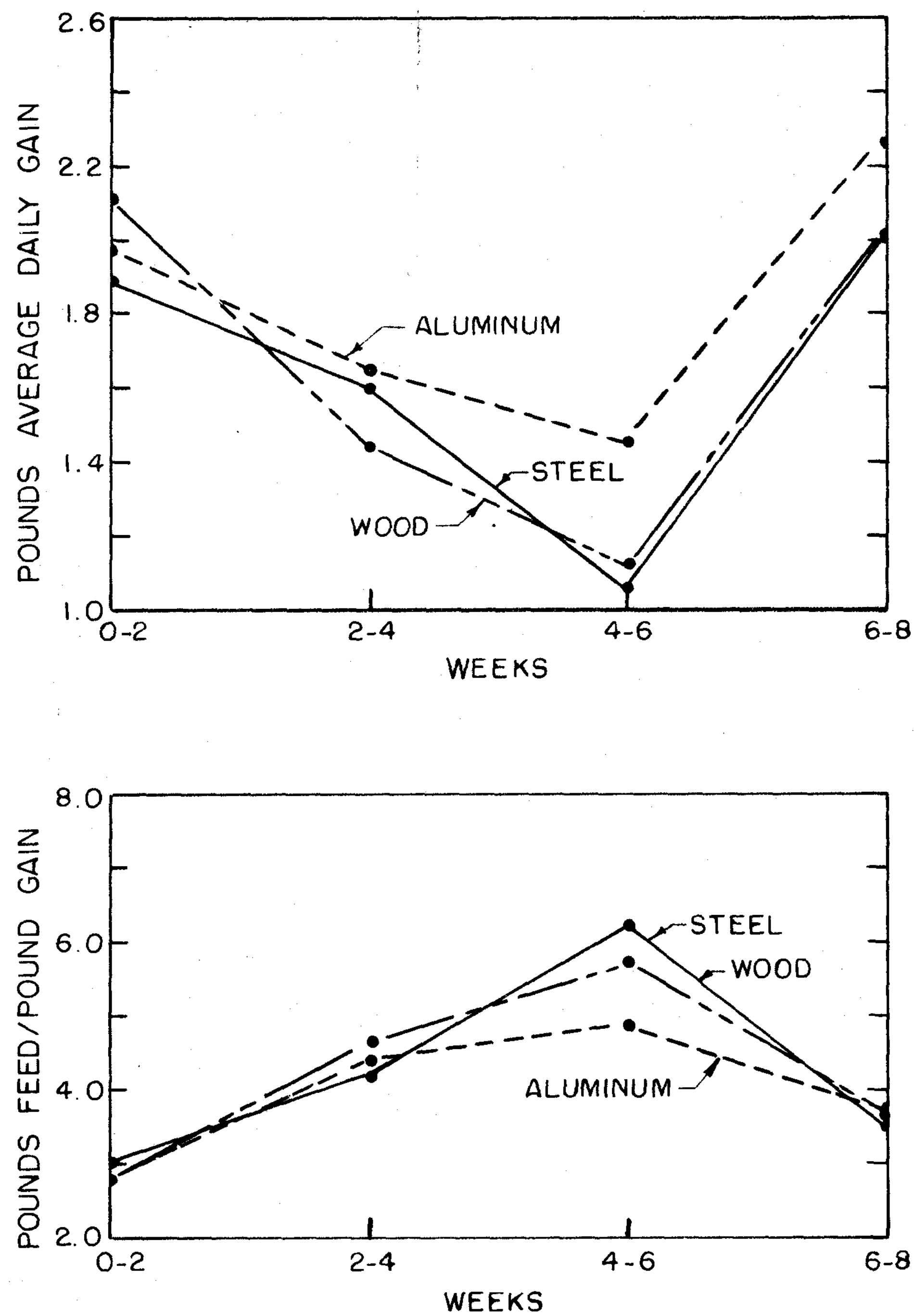


FIG. 23. AVERAGE FEED EFFICIENCY AND AVERAGE DAILY GAIN OF SWINE BY HOUSE TYPE WITH 4-6 WEEK PERIOD ADJUSTED 5 POUNDS - SUMMER 1955.

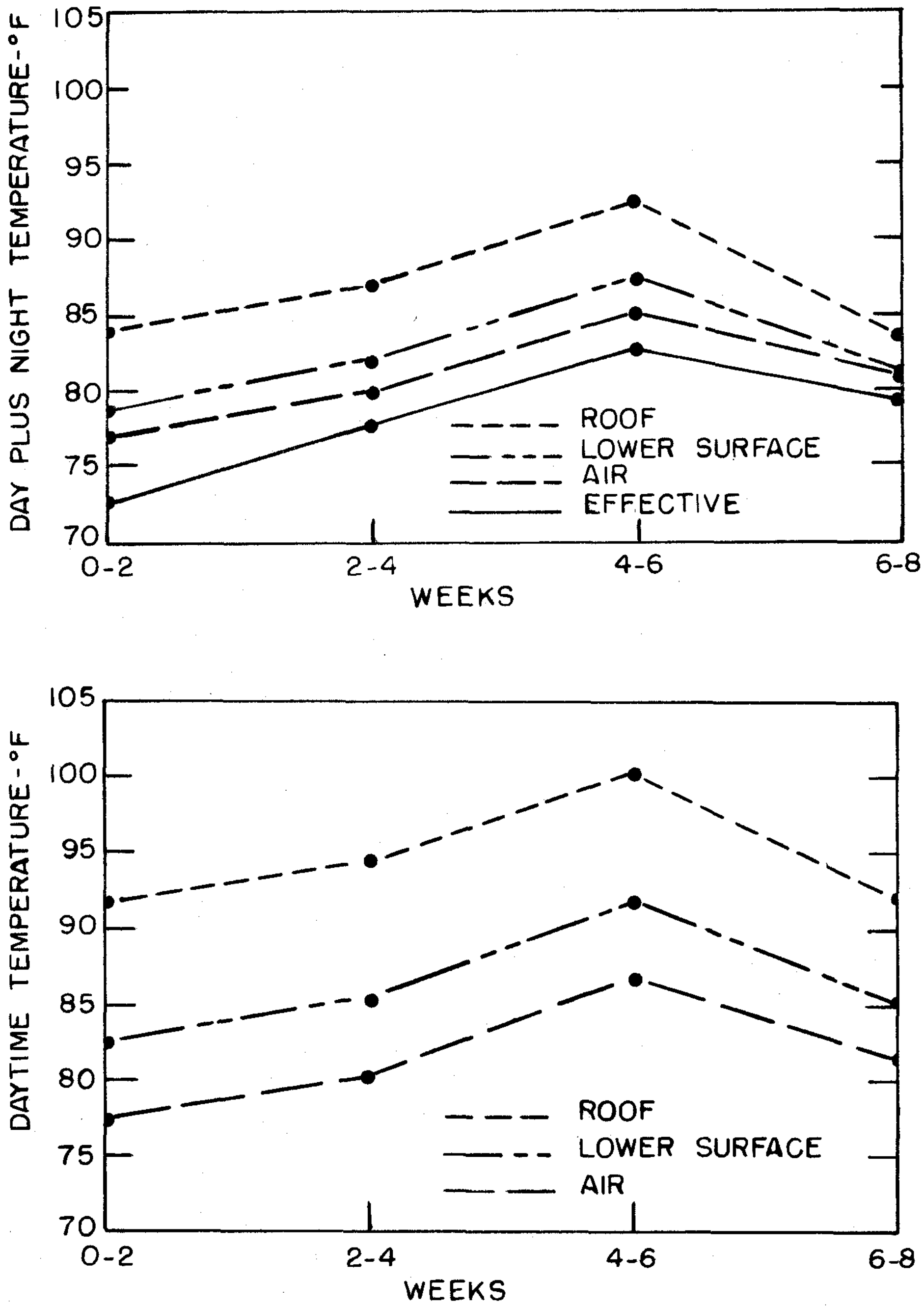


FIG. 24. COMPARISON OF INSIDE AVERAGE TEMPERATURES BY TWO-WEEK PERIODS. ALUMINUM HOUSES - SUMMER 1955.

Dale (6) developed a theoretical prediction equation for the inside air temperature within an enclosure which illustrates this dependency and later found a reasonably good experimental confirmation of reliability. Although the error in agreement between the experimental and the theoretical in Dale's tests is slightly larger than the differences in average values between house types for this study, this could be caused by values selected for emissivity and absorptivity of the materials tested.

The inside air temperature in each of the house types, during the peak outside air temperature period of the day (Figures 25,26,27), is computed in the Appendix using this equation. Averaged measured values for emissivity and values for absorptivity, corrected to compensate for changes resulting from aging and presence of foreign material on the surface, have been used in the equation and are, therefore, different from the estimated values as used by Dale.

Accumulated average of inside air temperature versus accumulated averages of daily gain and feed efficiency

The accumulative effect of environment on swine is shown by the accumulated averages for the entire study. Plots of the accumulated averages of feed efficiency and average daily gain versus inside air temperature at the 6 inch level are shown in Figure 28, each point through which the curve is fitted representing a house type. Slopes obtained from these are approximately 0.08 for feed efficiency and 0.09 for average daily gain; somewhat

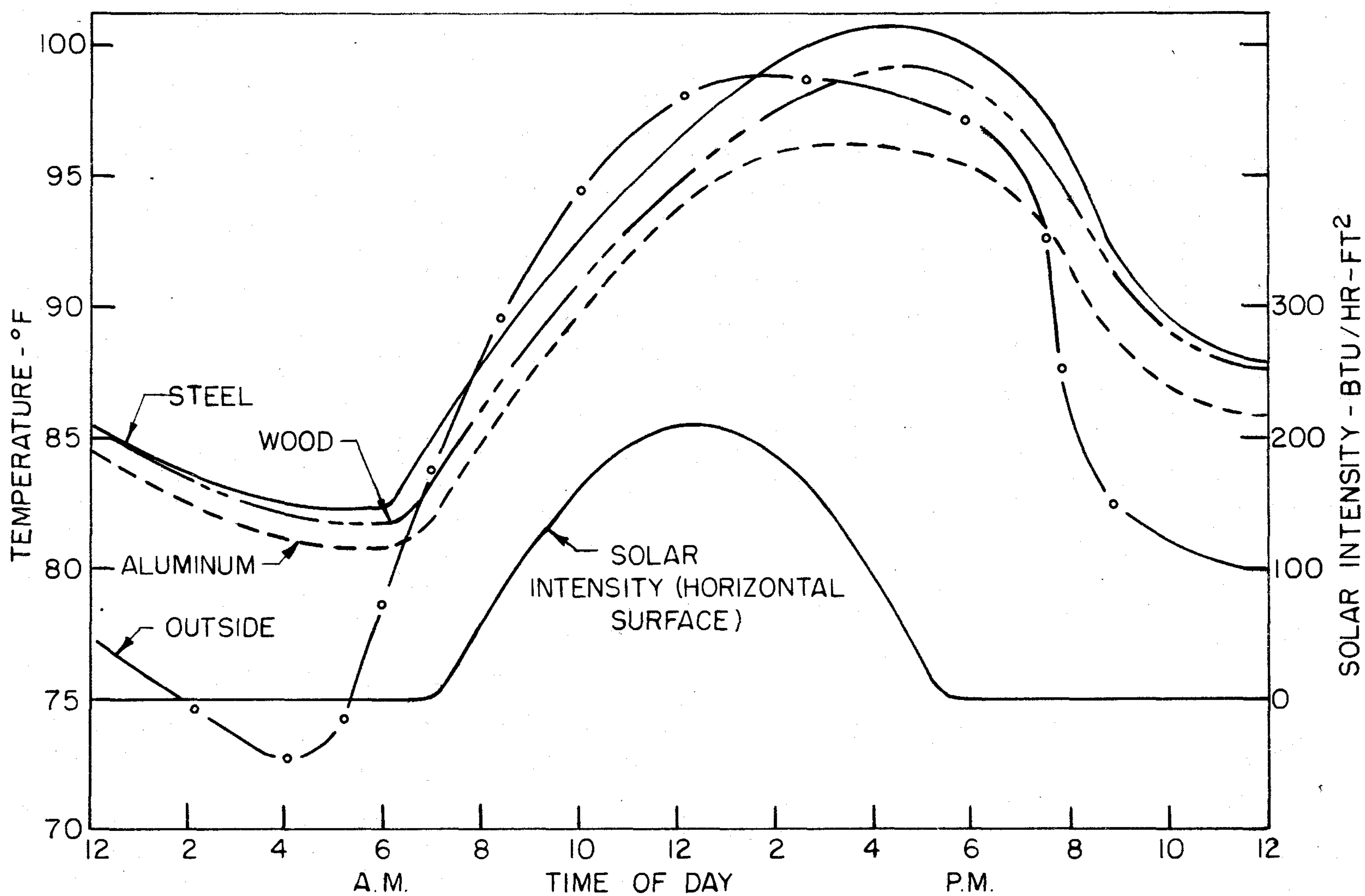


FIG. 25. INSIDE AVERAGE AIR TEMPERATURE BY HOUSE TYPE, OUTSIDE AIR TEMPERATURE, AND SOLAR INTENSITY - JULY 30, 1955.

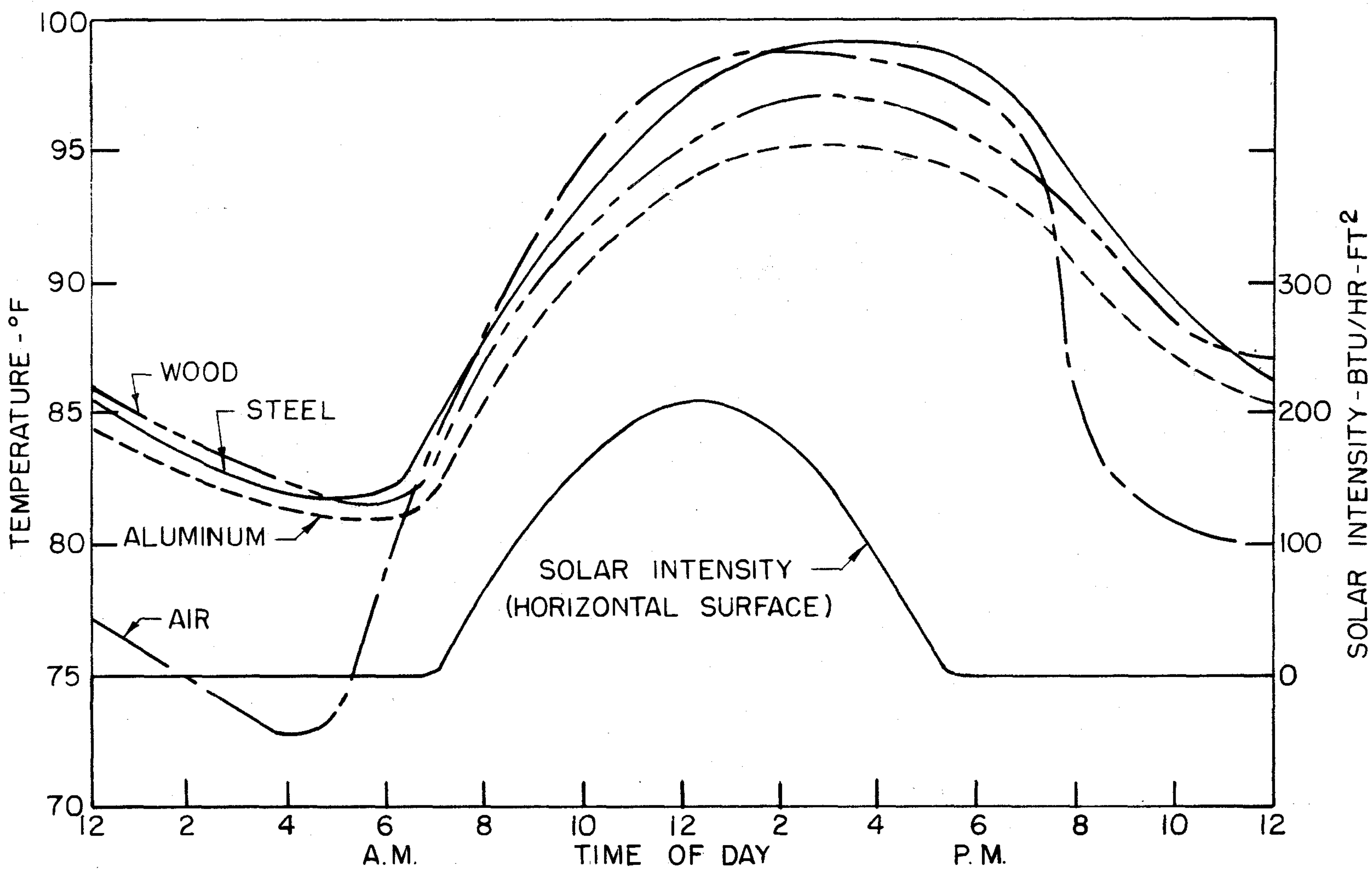


FIG. 26. INSIDE AVERAGE LOWER SURFACE TEMPERATURE, OUTSIDE AIR TEMPERATURE AND SOLAR INTENSITY - JULY 30, 1955.

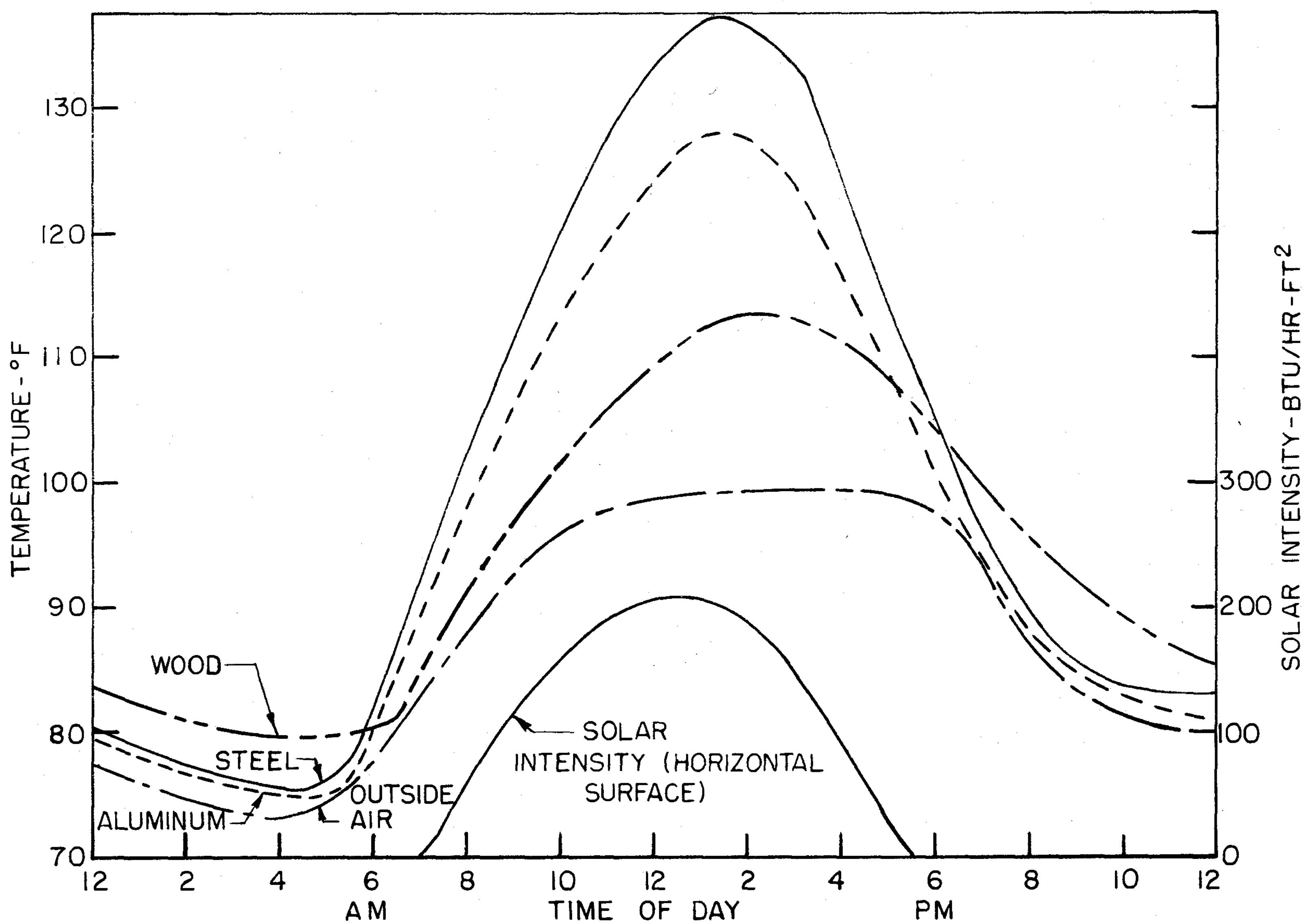


FIG. 27. INSIDE AVERAGE ROOF TEMPERATURES, OUTSIDE AIR TEMPERATURE AND SOLAR INTENSITY - JULY 30, 1955.

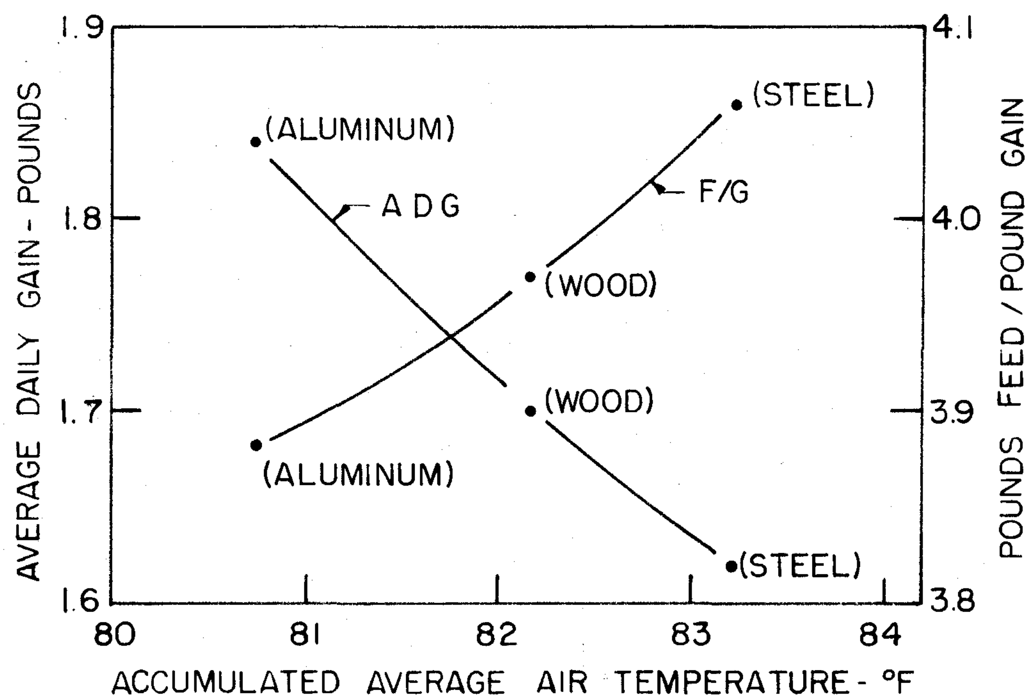


FIG. 28. ACCUMULATED AVERAGE INSIDE AIR TEMPERATURE, VERSUS AVERAGE DAILY GAIN AND AVERAGE FEED EFFICIENCY OF SWINE BY HOUSE TYPE - SUMMER 1955.

lower than those obtained by using averages of all house types by two-week periods.

A statistical analysis of effect of house type on accumulative feed efficiency and average daily gain reveals significance at the 5 percent level between the steel and the aluminum, and no significance between wood and metals. A summary of the analysis is in the Appendix.

Winter Study

The average weight gain and feed consumption by house and 2-week period during the winter study are given in Table 8. The initial and final average weights of the animals are in Table 9. Average air temperatures and relative humidities inside the houses for the winter test period are given in Table 10.

Although there was a measurable difference in air temperatures between the metal and wood houses (Figure 29), no effect can be shown on the animals. This indicates that under winter conditions, weaned pigs are not responsive to temperature differences of the magnitude occurring between the house types tested.

Feed efficiency and average daily weight gain, as plotted in Figure 30, when compared with values found under controlled conditions and reported in the literature (13) showed considerable differences for similar mean temperatures and pig size, i.e., 3.43 against approximately 5.0 pounds feed per pound of gain,

Table 8

Weight Gain and Feed Consumption of Pigs by House and 2 Week Period - Winter 1955-56

Rep. No.	House Type	0 - 2 Weight Gain Pounds	0 - 2 Feed Pounds	2 - 4 Weight Gain Pounds	2 - 4 Feed Pounds	4 - 6 Weight Gain Pounds	4 - 6 Feed Pounds	6 - 8 Weight Gain Pounds	6 - 8 Feed Pounds
	Aluminum	422	1308	416	1205	383	1407	380	1578
1	Steel	478	1331	384	1206	419	1499	421	1718
	Wood	517	1358	370	1195	413	1518	425	1677
	Aluminum	517	1485	352	1240	406	1485	384	1528
2	Steel	489	1424	375	1226	365	1431	440	1715
	Wood	500	1398	396	1169	402	1552	389	1648
	Aluminum	494	1475	353	1270	456	1647	485	1828
3	Steel	513	1511	353	1242	396	1520	448	1769
	Wood	524	1555	351	1241	425	1591	494	1673
	Aluminum	477.7	1422.7	373.7	1238.3	415.0	1513.0	416.3	1644.7
Avg.	Steel	493.3	1422.0	370.7	1224.7	393.3	1483.3	436.3	1734.0
	Wood	513.7	1437.0	372.3	1201.7	413.3	1553.6	436.0	1666.0

Table 9

Initial and Final Average Weights of Pigs by House - Winter 1955-56

Rep. No.	House Type	Initial Weight Pounds	Final Weight Pounds
	Aluminum	46.3	146.4
1	Steel	46.4	152.8
	Wood	45.9	153.7
	Aluminum	51.7	155.4
2	Steel	51.5	155.8
	Wood	51.6	157.0
	Aluminum	56.3	168.1
3	Steel	56.4	163.3
	Wood	56.1	168.3

Table 10

Average Air Temperature and Relative Humidity - Winter 1955-56

Week	Air Temperature of Aluminum	Air Temperature of Steel	Air Temperature of Wood	Relative Humidity Percent Aluminum	Relative Humidity Percent Steel	Relative Humidity Percent Wood
1	35.8	35.5	39.3	90	90	92
2	39.1	38.8	42.4	78	75	85
3	37.0	36.0	41.6	70	70	65
4	28.5	28.2	36.4	85	90	85
5	37.5	39.0	44.3	75	88	80
6	35.3	35.6	39.0	65	85	80
7	40.8	42.5	46.5	75	85	75
8	28.6	31.2	36.0	78	80	85

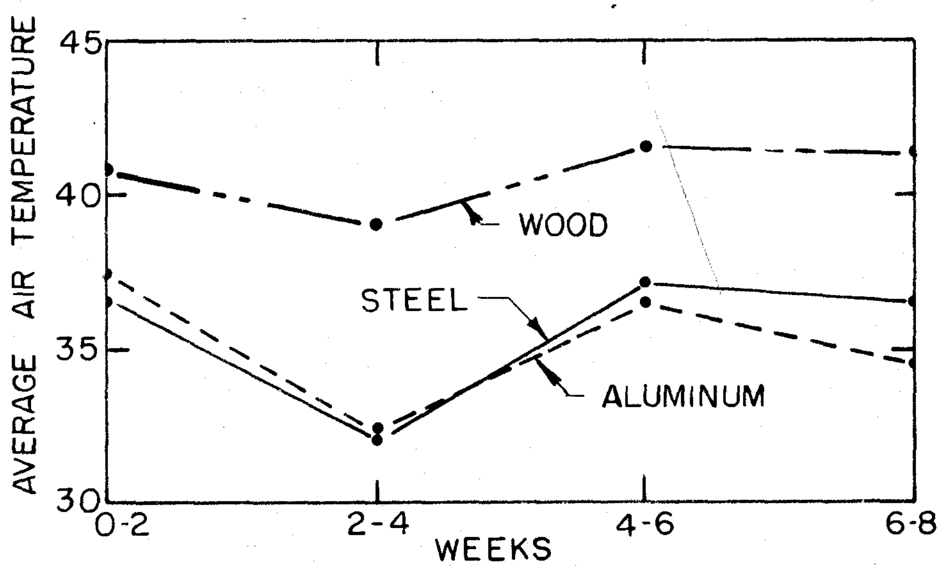


FIG. 29. AVERAGE INSIDE AIR TEMPERATURE - WINTER 1955-56.

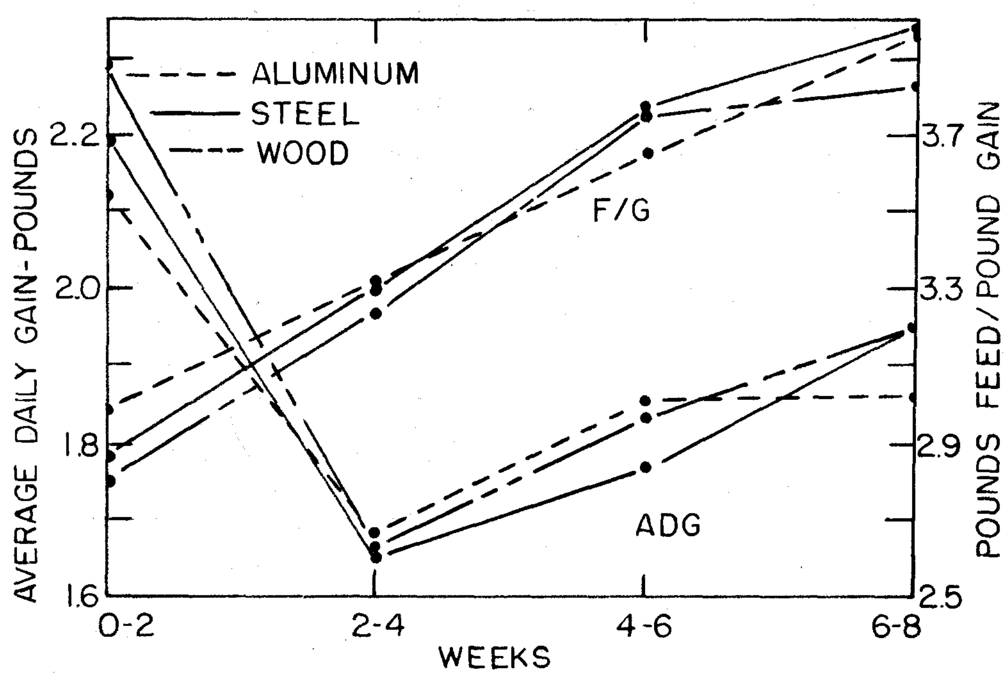


FIG. 30. AVERAGE DAILY GAIN AND FEED EFFICIENCY- WINTER 1955-56.

and 1.72 against approximately 1.2 pounds daily gain, the first values those found in this study.

DISCUSSION

Data previously presented in this thesis indicate a definite relationship between environment and feed efficiency under climatically varying conditions. A relationship also apparently exists between the environment and the rate of weight gain. It can be argued that the effects attributed to environment may be all or in part only natural occurrences in these measurements of animal well-being, evidence to substantiate these claims found in the literature. Statistically determined estimates in a report by Crampton (4) are that the decrease in feed efficiency due to age, for the stage of swine growth between 100 and 200 pounds (20 to 28 weeks of age), is approximately 0.8 pound of feed per pound of gain and the decrease is almost linear. At the same time Crampton indicates daily rate of gain to increase slightly reaching a peak at approximately 175 pounds, and then drop sharply at an approximate rate of 0.15 pounds per day for each 10 pounds of body weight increase.

Therefore, to reduce such effects if they influenced data in this thesis, correlations were computed using the average daytime temperature differences between house types for each two week period and the corresponding differences in rate of weight gain and feed efficiency. Errors which might have occurred in any period from weighing as well as the normal declines in feed efficiency effects were now minimized. A summary of the correlations is presented in the Appendix. One of these correlations shows that there is a highly significant relationship between the inside average daytime temperature at the 6 inch level (-0.82) and weight gain; that 65 percent of the decline in weight gain can be attributed to a temperature increase. The similar correlation with feed efficiency shows a low value for r (0.21); that only approximately 4 percent of the increase in feed efficiency can be attributed to temperature increase. However, the low feed efficiency correlation coupled with the high r value for weight gain, and the decline in feed consumption, suggests the effect of temperature increase is a reduction in appetite.

A correlation of weight gain and the average daytime surface temperatures raised to the fourth power and expressed in degrees Rankine, the latter an index of thermal radiation potential, gives a value for r which is just under significance at the 5 percent level (-0.36). This indicates approximately 13 percent of the weight gain decline can be attributed to radiation differences and also shows the much higher influence of air temperatures at the animal level.

As concerns the measurement of environment, the data indicate average inside air temperature to be an effective criterion for naturally varying conditions. This measure is one which can be comparatively easily obtained experimentally and might conceivably be extended for use in normal production programs.

Although the range of average temperatures is quite limited in this study, there is remarkable agreement between these data and the effects found under controlled conditions (13) in the same temperature range. An approximate equation from these limited data relating loss in weight gain with temperature increase (Figure 28) is

$$\Delta W = -0.08\,\Delta t$$

where ΔW is the loss in average daily gain (pounds) and Δt is the increase in average inside air temperature (°F.) applicable to growing pigs above 100 pounds raised under shelter during summer conditions. It is believed this equation is on the conservative side.

However, the data do not show either sufficient differences in any one measurement or consistency in relationship between animal responses in one type of house as compared with another to permit good statistical separation of the individual measurements and their relative importance in the overall influence. This prevents any reliable comparison at this time of experimental results with theoretical equations developed, and does not permit, by the same reasoning, the development of a prediction equation relating the effect of varying environment to the growth rate and feed efficiency of swine. Indications are at present, however, that the additional tests contemplated at the beginning of the project will increase the statistical reliability to the point that individual items can be evaluated.

Aside from the exact relationship between environment and animal efficiency, a comparison of feed efficiencies and rates of gain in the galvanized steel houses with those in the aluminum shows statistically significant differences of 0.2 pounds greater average daily gain and 0.18 pounds less of feed per pound of gain in the aluminum where the radiation and temperature measurements were lower than in the other house types. With present annual estimated feed cost for swine in Iowa (5) of 450 million dollars, an estimated average feed efficiency of 4 pounds per pound of gain, and slightly over 60 percent of the swine produced from spring farrowings, 0.18 pounds of feed per pound of gain represents a 20 million dollar annual expenditure in Iowa alone, or about 100 dollars per farm. The trend is towards raising pigs in confinement to obtain better nutritional and sanitary control.

It thus appears that environmental influences on livestock production efficiency are of sufficient economic importance to justify application of established information to shelter designs and also to warrant further serious study to extend the knowledge of these relationships.

SUMMARY

The long range objective of this work was to establish both theoretical and experimental relationships between various physical measurements of a naturally varying environment such as air temperature, thermal radiation, and relative humidity, and animal responses measured by feed efficiency and average daily gain of swine when housed in similar buildings but having different environments resulting from a difference in the building covering material. Of secondary importance was to compare these findings with those under controlled conditions as reported by others. This study presents an analysis of heat transfer relationships and reports on the findings of the first summer and winter tests in buildings designed for the investigation.

Nine houses were constructed, identical in design with the exception of the covering material, each house having four pens measuring 8 feet by 8 feet with separate watering and feeding equipment in each pen. Two additional units were also constructed to serve as feed and bedding storage and to act as guard units, thus providing end animal units with the same exposure as those intermediate. Equipment and utilities were selected or of special design to assure uniformity of ventilation, drinking water temperature, and heat from other than animal sources inside the units. Covering materials selected were corrugated embossed aluminum, corrugated galvanized steel, and wood carsiding with an asphalt shingle roof over solid sheathing, three units of each covering material constructed.

The summer test used 72 pigs averaging 110 pounds each at the start and carried over an 8-week period to an average final weight of approximately 205 pounds each. The winter test used four animals per pen, 144 in all, starting at approximately 45 pounds each and continuing through an 8-week period to approximately 155 pounds each.

Thermocouple measurements of the inside air temperature at different levels, with the majority of these thermocouples at the animal level (6 inches above the floor), thermocouple measurements of the inside surface temperatures of the walls and roof, and hygrothermograph readings of relative humidity were recorded continuously in one unit of each of the three types. Periodic measurements at selected test points were taken in the remaining six houses to provide reliability of projection of the continuously recorded measurements to all houses. Radiometer readings of the various inside surfaces, to aid in the measurement of surface emissivities, and surveys of the interiors with the radiometer from a standard position, to give an index of thermal radiation intensity, were also taken periodically.

Animals were selected for nearly equal hereditary and growth characteristics, randomly placed in the houses, fed the same ration, provided the same temperature of drinking water, and managed as uniformly as possible. Animal weight and feed consumption were recorded at 2-week intervals. Free-choice of feed and water was practiced, special techniques and equipment designs described.

During the summer study animals in the aluminum covered units where temperatures were lowest had the most rapid growth and the highest feed efficiency, gaining 0.2 pounds per day more on 0.18 pounds less feed per pound of gain than those in the galvanized steel, and about 0.1 pounds per day more gain on 0.1 pounds less feed per pound of gain than those in the wood. These differences were found to be significant in the comparison of aluminum and galvanized steel, and not significant between aluminum and wood or wood and steel.

No significant differences were found in either average daily gain or feed efficiency during the winter study although there were measureable differences in environments between the house types.

Average inside air temperature at the animal level was found to be sufficiently dependent on other temperatures that it could be used as a criterion for judging environment. A correlation designed to eliminate natural growth effects on feed efficiency and average daily gain gave a highly significant comparison of this measurement between approximately sunrise and sunset and that of average daily gain, but a low correlation coefficient value when compared with feed efficiency. Coupled with a decline in feed consumption with temperature rise, this indicated the effect of a rise in temperature during the summer on heavy pigs to be a reduction in appetite.

Comparison of the animal responses in the summer study with those reported by others using controlled conditions shows good agreement for the same mean temperature range, but pigs in the winter study performed noticeably better in terms of feed efficiency and rate of weight gain if judged by values reported for similar mean temperatures under controlled conditions.

Difficulty was encountered in establishing the inside surface emissivity values due to the continual change of dirt and manure accumulation. Sensitivity of the relative humidity equipment was also affected by dust accumulation and an experimental wet-bulb unit to correct this trouble is discussed. The radiometer showed influence of effects other than thermal radiation which reduced the value of measurements thus obtained.

The presence of wet floors and substantial cooling of the buildings during the nights are believed to have been largely responsible for the better than anticipated summer gains and feed efficiencies.

SUGGESTIONS FOR FURTHER STUDY

1. Additional tests are needed to reduce the statistical experimental error term by increasing the number of observations and thus definitely substantiate or deny the indication of effect of difference in the environments found in the first summer study. Plans are already prepared, and work underway to continue this study in the summer of 1956.

2. Methods for evaluating radiation exchange between the animal and the enclosure using surface temperatures, or other easily obtained measurements, are needed.

3. Whether an animal is affected by the emissivity of the building surfaces surrounding it or whether radiation exchange is dependent only upon the temperature of the surfaces needs investigation. It is believed that this can be accomplished with the facilities used in this study by painting the inside surfaces of one or more of the aluminum buildings black and comparing the development of animals thus housed with those in unpainted units.

4. Simultaneous studies comparing animals under varying climatic tests with others of similar hereditary and growth characteristics under controlled environment are needed to better establish the relationship between the results obtained by the two methods of testing. With new facilities for environmental control being developed at this college, it is hoped these may be initiated.

Table 11

Nomenclature

Symbol	Identification	Dimensions	Standard Units
A_s, A_1, A_2	Surface area of enclosure where subscripts refer to enclosures s, 1, and 2 respectively	L^2	ft^2
A_a	Surface area of animal	L^2	ft^2
b,c	Energy ratios of feed	$HT^{-1}F^{-1}$	BTU/hr lb
d	Energy ratio of body weight	$HT^{-1}F$	BTU/hr lb
e_s, e_1, e_2	Emissivity of enclosure where subscripts refer to enclosures s, 1, and 2 respectively	Dimensionless	---
e_a	Emissivity of animal surface	Dimensionless	---
ΔF	Difference in feed consumption	F	lb
F_a	Shape factor	Dimensionless	---
F_e	Emissivity factor	Dimensionless	---
f, f_1, f_2	Function	Dimensionless	---
ΔG	Difference in feed consumption	F	lb
$\Delta h, \Delta h_1, \Delta h_2$	Enthalpy difference between incoming and respired air where subscripts refer to enclosures 1 and 2 respectively	HF^{-1}	BTU/lb

Table 11 (Continued)

Symbol	Identification	Dimensions	Standard Units
h_1, h_2	Enthalpy of air in enclosure where subscripts refer to enclosures 1 and 2 respectively	HF^{-1}	BTU/lb
K	Surface conductance coefficient for natural convection	$HT^{-1}L^{-2}\theta^{-1}$	BTU/hr ft^2 °F.
Q	Heat production or heat transfer where subscripts are as follows: a — animal $a \rightarrow s, s \rightarrow a$ — from animal to enclosure and enclosure to animal respectively c, c_1, c_2 — convection where subscripts refer to environments 1 and 2 respectively	HT^{-1}	BTU/hr
Q_{net}	Difference in heat transfer or heat production	HT^{-1}	BTU/hr
q	Rate of heat transfer	$HT^{-1}L^{-2}$	BTU/hr ft^2
r, r_w	Respiration rate	FT^{-1}	lb/hr
S	Stephan-Boltzman Constant of radiation	$HT^{-1}L^{-2}\theta^{-4}$	BTU/hr °R^4 ft^2

Table 11 (Continued)

Symbol	Identification	Dimensions	Standard Units
T_s, T_1, T_2	Absolute temperatures where subscripts s, 1, and 2 refer to enclosures s, 1, and 2 respectively	θ	^oR
T_a	Absolute temperature of animal surface	θ	^oR
T_{si}	Effective radiant temperature or equivalent black body temperature	θ	^oR
t_a	Temperature of animal	θ	^oF
t_{air}, $(t_{air})_1$, $(t_{air})_2$	Temperature of air where subscripts 1 and 2 refer to enclosures 1 and 2 respectively	θ	^oF
W	Weight	F	lbs

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APPENDICES

Appendix 1

Computation of Inside Air Temperature(Using Equation 18, Page 31, A. C. Dale. The Effect of Roofing Materials on Temperatures in Farm Buildings. Unpublished Ph. D. Thesis. Iowa State College Library, Ames, Iowa. 1950.)

Basic Equation:

$$t_i = t_o + \frac{I_i a\left(1 - \frac{R_x}{R_t}\right)}{(h_{co} + h_{ro}) + (UK + Mc)\left[1 + \frac{h_{co} + h_{ro}}{h_{ci} + h_{ri}}\right] - \frac{R_x}{R_t}(UK + Mc + h_{co} + h_{ro})}$$

Sub Equation:

$$\frac{R_x}{R_t} = \frac{t_{os} - t_{is}}{t_{os} - t_i},$$ where t_{is} and t_{os} are inner and outer roof surface temperatures respectively

For steel or aluminum over spaced sheathing $\frac{R_x}{R_t} = 0$ and

$$t_i = t_o + \frac{I_i a}{(h_{co} + h_{ro}) + (UK + Mc)\left[1 + \frac{h_{co} + h_{ro}}{h_{ci} + h_{ri}}\right]}$$

Definition of terms:

$K = \frac{\text{area wall}}{\text{area roof}} = \frac{A_w}{A_r}$

t_i, t_o = inside and outside air temperatures respectively ^{o}F.

$I_i = \frac{I_h \cos i}{\cos i_h}$ where I_h = pyrheliometer reading in BTU/ft^2 hr
i_h = angle to pyrheliometer of normal rays
i = angle of rays to surface

Mc = mass of ventilating air in lbs/hr ft^2 of roof surface x specific heat of air in BTU/lb ^{o}F.

h_{co}, h_{ci} = outside and inside convection coefficients in BTU/ft^2 hr ^{o}F.

h_{ro}, h_{ri} = outside and inside surface radiation coefficients in BTU/ft^2 hr ^{o}F.

a = absorptivity

e = effective emissivity

U = overall coefficient of heat transfer through walls in BTU/ft^2 hr ^{o}F.

Appendix 1 (Continued)

Values for coefficients used to predict temperature on July 30, 1955, in swine houses.*

Data: Time 1:30 - 2:30 p.m.

t_o = 98°F., wind @ 7 m.p.h., I_i = 217 BTU/hr ft^2

	Aluminum	Steel	Wood
h_{co}	(2.35)	(2.35)	(3.6)
h_{ci}	(0.3)	(0.3)	(0.3)
e	0.35 (0.11)	0.65 (0.28-0.42)	0.80 (0.88)
a	0.35 (0.26)	0.65 (0.66-0.89)	0.80 (0.89)

K - estimated all buildings = 0.60
based on roof + 1/4 walls receiving, 3/4 walls + 1/3 floor losing

U	(0.69)	(0.77)	(0.48)

Mc - estimated for all buildings @ 1800 lbs/hr or 400 cfm = 0.72
equivalent to 3 lbs/ft^2 hr of receiving area

h_r from equation based on chart values in Dale

$$h_r = e\left[1.44 - 0.003\,\Delta t - 0.006(140-x)\right]$$

where x = surface temperature
Δt = temperature of surface - temperature of air
e = emissivity of surface

h_{ro}	0.39	0.86	1.08
h_{ri}	0.39	0.86	1.02
$\frac{R_x}{R_t}$	0	0	$\frac{27}{40} = 0.68$

* Values in parenthesis from reference.

Appendix 1 (Continued)

First Approximation

Aluminum:

$$t_i = 98 + \frac{(217)(0.35)}{(2.35 + 0.3) + \left[(0.69)(0.6) + 0.72\right]\left[1 + \frac{2.35 + 0.39}{0.3 + 0.39}\right]}$$

$$= 98 + \frac{75.95}{8.11} = 107.36^{\circ}\mathrm{F.} \qquad \text{measured} = 94^{\circ}\mathrm{F.} @ 6'' \quad 103^{\circ}\mathrm{F.} @ 7'$$

Steel:

$$t_i = 98 + \frac{(217)(0.65)}{(2.35 + 0.3) + \left[(0.77)(0.6) + 0.72\right]\left[1 + \frac{2.35 + 0.86}{0.3 + 0.86}\right]}$$

$$= 98 + \frac{141.05}{7.10} = 117.86^{\circ}\mathrm{F.} \qquad \text{measured} = 96^{\circ}\mathrm{F.} @ 6'' \quad 111^{\circ}\mathrm{F.} @ 7'$$

Wood:

$$t_i = 98 + \frac{(217)(0.8)(1 - 0.68)}{(3.6 + 0.3) + \left[(0.48)(0.6) + 0.72\right]\left[1 + \frac{3.6 + 1.08}{0.3 + 1.02}\right]}$$

$$\overline{-0.68\ (0.29 + 0.72 + 2.15 + 1.08)}$$

$$= 98 + \frac{56.42}{5.61} = 108.06^{\circ}\mathrm{F.} \qquad \text{measured} = 95^{\circ}\mathrm{F.} @ 6'' \quad 105^{\circ}\mathrm{F.} @ 7'$$

Steel - aluminum = 117.86 - 107.36 = 10.5°F. measured = 2°F. @ 6" 8°F. @ 7'

Wood - aluminum = 108.06 - 107.36 = 0.7°F. measured = 1°F. @ 6" 2°F. @ 7'

Appendix 2

Statistical Analyses
Summer 1955

Period	Average Inside Air Temperature at 6" above Floor °F. during Daytime				(Average Inside Surface Temperature in Daytime)^4 x 10^{-8} °R.		
	Aluminum	Steel	Wood	Total	Aluminum	Steel	Wood
1	77.93	79.51	79.53	236.97	866.25	904.00	867.77
2	80.72	83.64	82.48	246.84	883.87	933.17	890.71
3	86.79	89.49	87.91	264.19	925.08	964.41	925.00
4	81.70	85.26	82.47	249.43	882.30	930.32	885.13

	Average 2-week Gains - lbs				Average Feed Efficiency lbs feed/lb gain		
Rep. 1							
1	281	270	269	820	2.76	2.76	2.74
2	206	170	161	537	4.40	4.56	4.70
3	216	159	157	532	3.93	4.77	4.55
4	229	202	200	631	4.46	4.21	4.16
	932	801	787	2520			
Rep. 2							
1	197	178	228	603	2.82	3.29	2.93
2	157	186	173	516	4.63	3.96	4.64
3	210	173	192	575	3.58	4.21	3.76
4	197	183	180	560	4.32	4.31	4.75
	761	720	773	2254			
Rep. 3							
1	182	187	215	584	2.92	3.15	2.71
2	186	181	153	520	4.21	4.08	4.60
3	184	143	151	478	4.24	5.07	4.87
4	214	176	180	570	4.26	4.38	4.46
	766	687	699	2152			

Appendix 2 (Continued)

A. Test for "F" between house types.

Average Daily Gain - Total Period

Source	d.f.	ss	ms	s	F	F@0.05	Significance
Replications	2	0.3510	0.1755				
Type of house	2	0.5498	0.2749		4.08	6.94	
Between metals	1	0.5440			8.07	7.71	@5%
Metals vs wood	1	0.0058			0.08	7.71	n.s.
Error (a)	4	0.2696	0.0674	0.2596	C.V.15.18	5.36	
Total	8	1.1704					
Position in house	3	0.1291	0.0425				
S vs N	1	0.1035					
W vs E	1	0.0210					
S vs N x W vs E	1	0.0045					
Position x type	6	0.5737	0.0956				
Error (b)	18	1.1576	0.0643				
Total	35	3.0308					
Sex	1	0.1871			3.90	4.18	
Sex x type	2	0.0383	0.0192				
Sex x positions	3	0.0788	0.0263				
Error (c)	29	1.3919	0.0480				
Total	70	4.7269					

Average Feed Efficiency for Total Period

Source	d.f.	ss	ms	s	F	F@0.05	Significance
Replications	2	0.1717	0.0858				
Type of house	2	0.2072	0.1036		4.86	6.94	
Between metals	1	0.2072			9.73	7.70	@5%
Metals vs wood	1	0.000			----	7.70	n.s.
Error (a)	4	0.0852	0.0213				
Total	8	0.4641					
Position in house	3	0.2223					
S vs N	1	0.0427					
S vs N x W vs E	1	0.1792			4.95	4.45	
W vs E	1	0.0004					
Position x type	6	0.2447	0.0408				
Error (b)	17	0.6152	0.0362				
Total	34	1.5463					

Appendix 2 (Continued)

B. Correlation values (multiple correlation to minimize effects of age and intermediate weigh periods)

Feed Efficiency vs Daytime Temperature at 6" above Floor

Source	d.f.	Sxy	Sx^2	Sy^2	m.s.	r	Significance
Sub groups	11	52.6029	379.7963	16.1657			
Replications	2						
Periods	3						
Rep x per	6						
Remainder	24	2.1128	50.1178	1.8768	2.0882	+0.2178	n.s.
Total	35	54.7152	429.9141	18.0425	(temp.)		

Weight Gain vs Daytime Temperature at 6" above Floor

Source	d.f.	Sxy	Sx^2	Sy^2	m.s.	r	Significance
Subgroups	11	-1728.19					
Replications	2						
Periods	3						
Rep x per	6						
Remainder	24	-571.72	50.1178	9619	2.0882	-0.8234	@1%
Total	35	-2300.91	429.9141	37429	(temp.)		

Weight Gain vs (Average Daytime Surface Temperature)^4
values coded by (avg. temp.)^4 x 10^{-8} - 800

Source	d.f.	Sxy	Sx^2	Sy^2	m.s.	r	Significance
Subgroups	11	-11714.34	16173.3155	16.1657			
Replications	2						
Periods	3						
Rep x per	6						
Remainder	24	-4269.30	14476.1818	1.8768		-0.3617	slightly less than 5%
Total	35	-15983.64	30649.4973	18.0425			

Appendix 3

Sample of Thermocouple Readings

Table 12. Sample of Thermocouple Readings as Obtained from Brown Potentiometer Chart

Date and Time	Thermocouple No. 5	6	7	8	9	10	11	12	13	14	15	17	19	20	21	22	23	25	26
Wood House °F.																			
July 6, 1955																			
6 am	76	77	76	69	76	76	76	76	76	76	76	76	76	76	76	77	77	79	77
10 am	82	82	82	77	80	82	82	84	82	82	84	80	80	80	80	80	80	80	83
1 pm	87	87	87	83	84	88	87	87	87	88	84	84	85	85	85	86	88	90	90
3 pm	84	83	83	74	83	83	83	84	84	83	83	83	80	80	81	82	82	83	83
6 pm	84	83	83	80	83	83	83	83	83	83	83	83	80	80	80	81	83	82	85
10 pm	80	80	80	72	80	80	80	82	82	81	81	80	84	84	80	81	81	79	80
July 7, 1955																			
4 am	76	76	76	68	77	76	76	76	76	76	76	76	76	76	76	76	77	76	77
11 am	88	87	88	87	88	85	90	89	92	89	90	91	84	85	87	87	87	88	89
6 pm	89	88	88	89	88	86	88	88	88	88	88	88	83	83	85	86	86	92	92
11 pm	82	82	82	80	82	82	82	82	82	82	82	80	80	80	80	80	84	82	82
Steel House °F.																			
July 6, 1955																			
6 am	76	76	76	69	77	77	76	76	76	82	77	76	76	76	76	76	76	76	76
10 am	83	83	83	75	83	80	83	83	86	83	83	85	81	83	80	80	80	78	82
1 pm	88	87	85	81	87	87	88	88	88	88	88	87	87	87	85	86	84	83	88
3 pm	81	82	82	74	82	82	82	82	82	82	82	81	81	81	81	80	80	80	81
6 pm	83	83	83	80	83	83	83	83	83	83	83	83	83	84	82	82	81	84	89
10 pm	80	80	80	72	84	80	80	80	80	80	80	80	80	80	80	80	80	80	80
July 7, 1955																			
4 am	75	75	75	68	75	75	75	78	75	76	76	75	75	75	75	75	75	75	75
11 am	90	90	87	87	86	86	90	90	95	90	91	88	88	94	90	90	89	85	90
6 pm	90	88	86	85	87	88	88	88	88	88	88	88	88	88	88	88	88	88	90
11 pm	82	82	80	80	82	82	82	82	82	82	82	86	85	83	83	83	83	88	85

Appendix 3 (Continued)

Date and Time	5	6	7	8	9	10	11	12	13	14	15	17	19	20	21	22	23	25	26
	Aluminum House °F.																		
July 6, 1955																			
6 am	76	76	76	69	77	77	76	76	76	82	77	76	76	76	76	76	76	76	76
10 am	79	79	79	76	79	79	80	80	80	80	80	88	80	81	80	80	80	80	80
1 pm	82	82	82	83	83	83	83	83	83	83	83	83	82	82	82	82	82	83	85
3 pm	78	78	78	75	81	81	81	81	80	80	80	79	79	79	79	78	79	85	82
6 pm	82	82	82	80	82	82	82	82	82	82	82	82	80	80	80	80	80	81	85
10 pm	77	77	78	72	80	80	80	83	80	80	80	78	79	79	79	79	79	79	79
July 7, 1955																			
4 am	75	77	76	68	76	76	76	76	78	76	76	76	76	76	76	76	76	77	77
11 am	86	85	86	87	86	86	85	85	89	86	86	86	86	88	85	85	85	86	86
6 pm	87	85	86	85	87	86	86	86	86	86	86	86	86	86	86	86	85	85	85
11 pm	81	81	81	80	81	81	80	81	81	81	81	80	81	81	81	81	81	80	80

Above the thermocouple numbers the table prints the heading "Thermocouple No.".

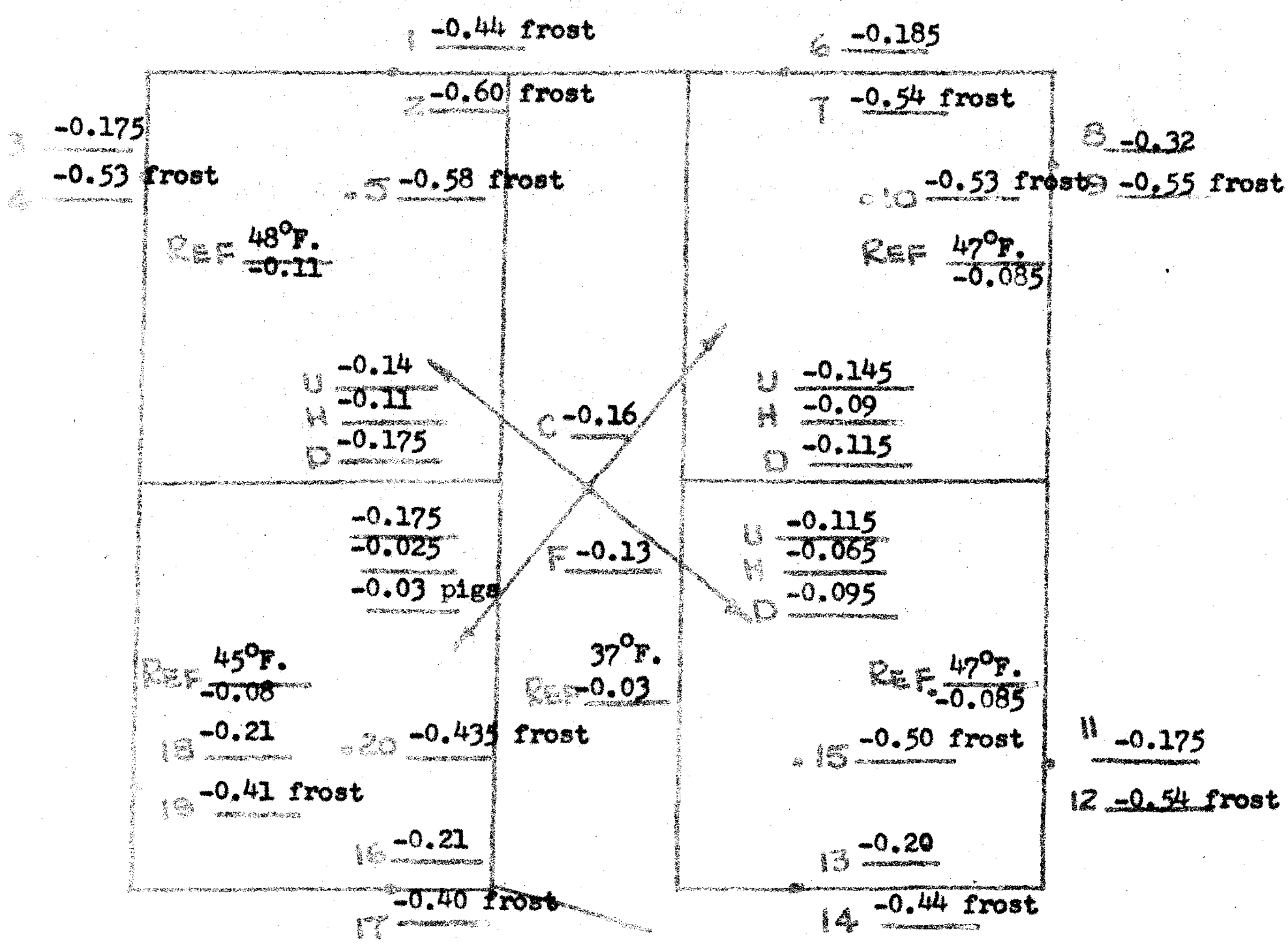
July 6, 1955 Heavily overcast, cool, winds out of SE @ 3 - 8 mph (variable).

July 7, 1955 Sunny with occasional light clouds, mild, light breeze from south.

Appendix 4
Form for Recording Radiometer Data
and Typical Sample of Data

RADIOMETER DATA

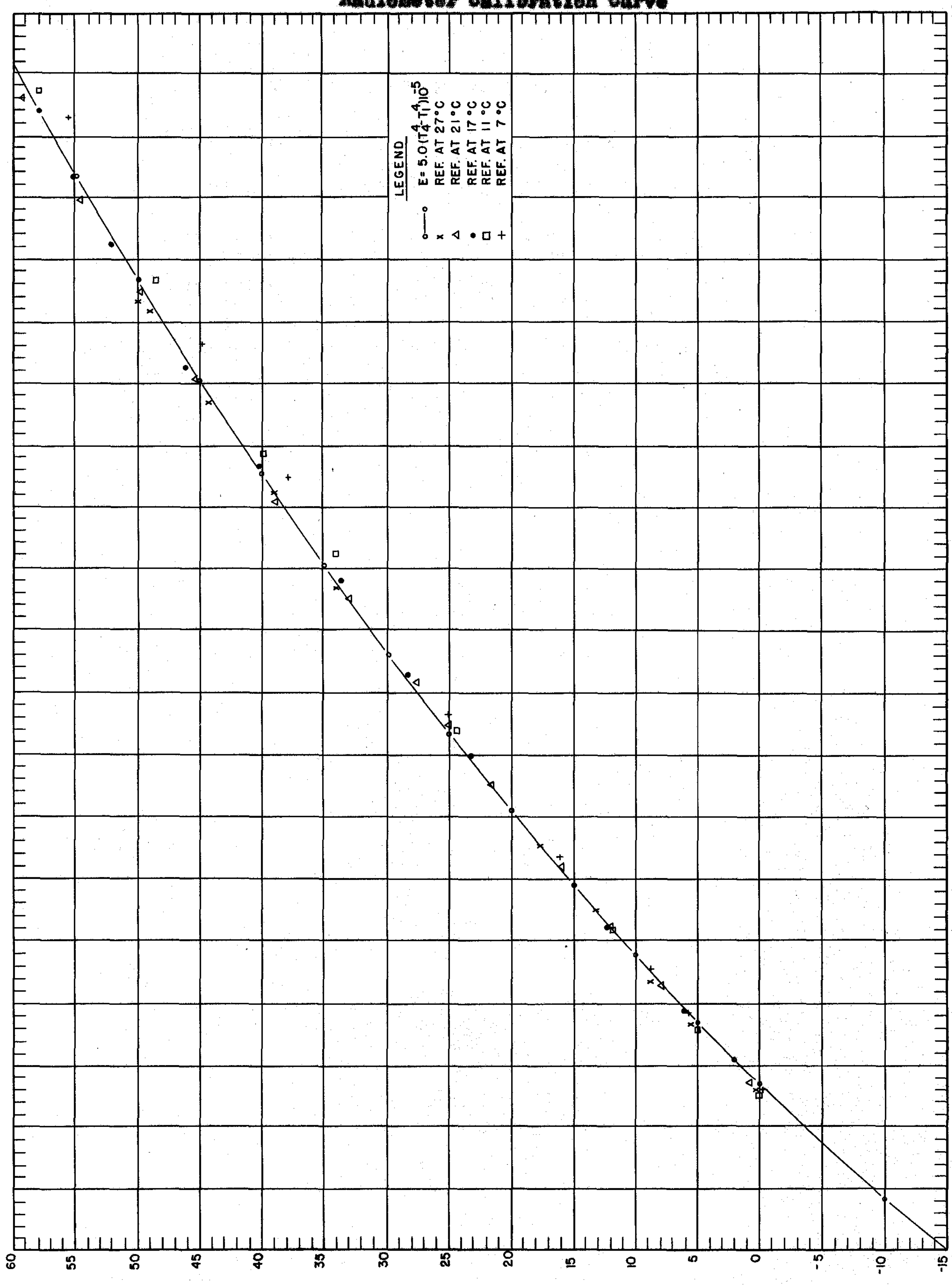
SURFACE MEASUREMENTS
(Millivolts)



DATE 1-7-56 TIME Surface 9:40-9:50 am
Survey 10:25-10:30 am HOUSE G-6
Aluminum

1st No. - lower panel
2nd No. - Upper panel
U - Up 45° C - Ceiling
H - Horizontal F - Floor
D - Down 22.5°

Appendix 5
Radiometer Calibration Curve



CALIBRATION CURVE - BIS.,TIN - BIS.,ANTIMONY, 8-JUNCT. THERMOPILE

Appendix 6

Experimental Rations

Basal Ration (incl. % Protein)	14%	12%	10%
Gr. Yellow Corn	79.8	85.6	91.05
Dehy. Alfalfa	2.5	2.5	2.5
Meat & Bone Scraps	2.5	2.5	2.5
Fish Solubles	1.0	1.0	1.0
Soybean Oil Meal	12.0	6.5	1.0
Calcium Carbonate	0.5	0.6	0.55
Dicalcium Phosphate	1.0	0.6	0.7
Iodized Salt	0.5	0.5	0.5
Trace Minerals	0.05	0.05	0.05
Lederle 2-4-9C	0.05	0.05	0.05
Lederle Aurofac 10	0.05	0.05	0.05
Lederle Profactor B	0.05	0.05	0.05
Vitamin D_2 (142-F)	0.25 gm./100	0.25 gm./100	0.25 gm./100

14% used for young pigs in winter test.

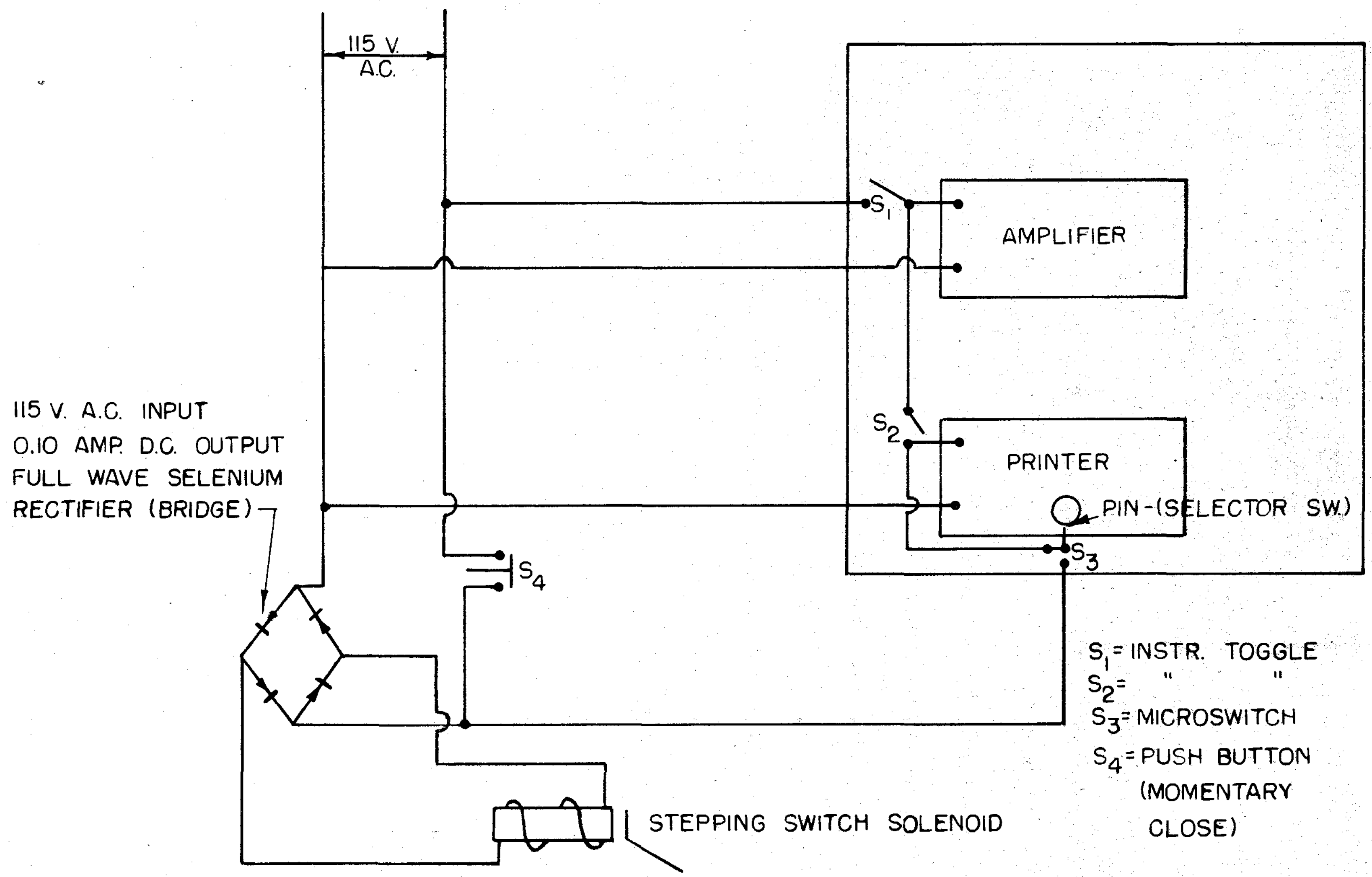


FIG. 31. CONTROL CIRCUIT - CONNECTIONS TO POTENTIOMETER

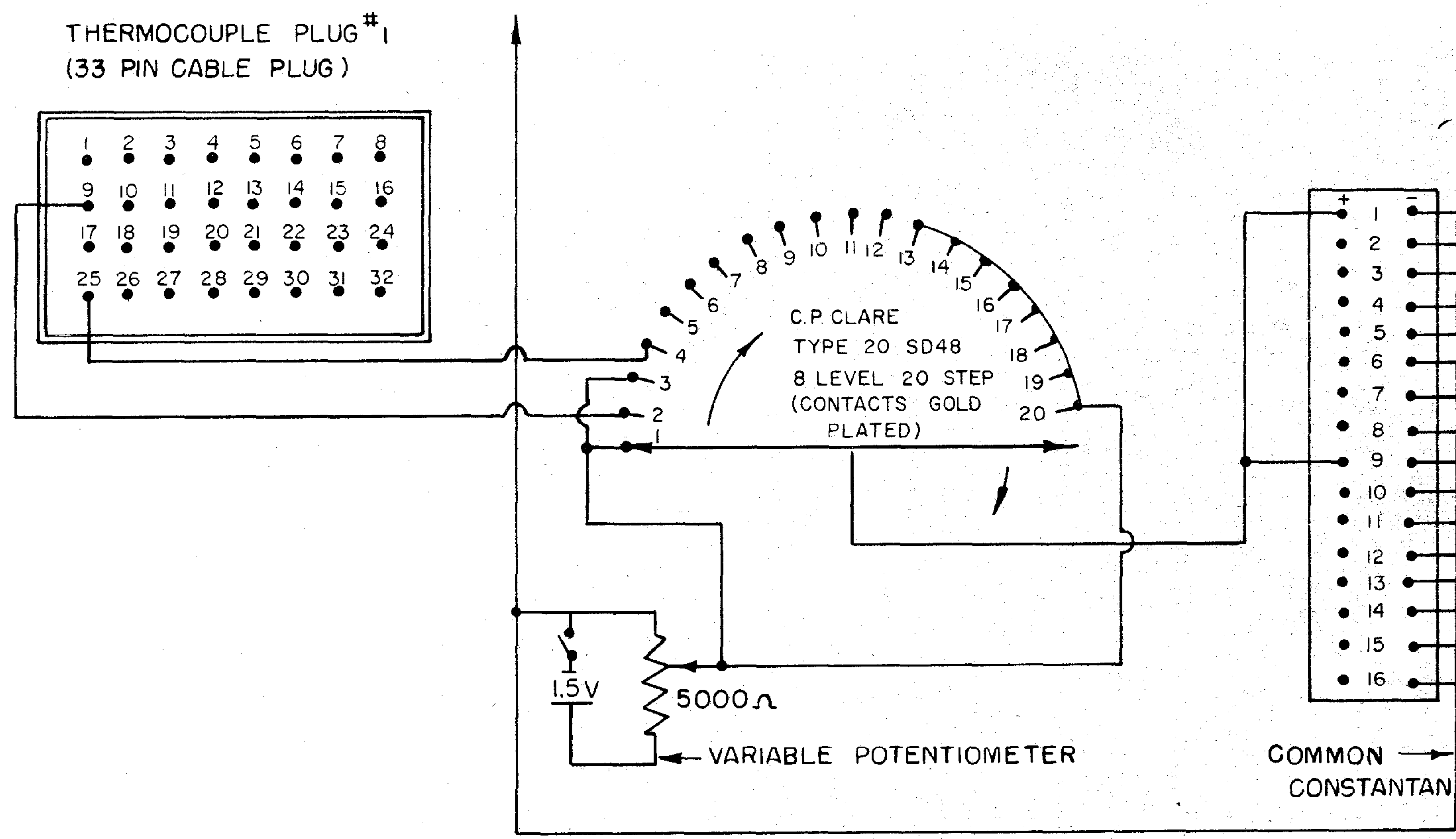


FIG. 32. THERMOCOUPLE SWITCHING CIRCUIT.
(LEVEL 1; AND 1 OF 3 PLUGS)